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EVALUATION OF AN OPTIMAL SPREAD ANGLE
FOR A COMBINED FAST PATROL BOAT SECTOR ATTACK
WITH TORPEDOES AGAINST ONE DESTROYER

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by

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September 1971

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Evaluation of an Optimal Spread Angle
for a Combined Fast Patrol Boat Sector Attack
with Torpedoes Against One Destroyer

by

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

A computer model has been developed in order to determine an optimal spread angle for a combined Fast Patrol Boat sector attack with torpedoes against one destroyer. The scenario considered consisted of ten Fast Patrol Boats (Type 55/60) of the German Navy with four torpedoes (Mk 8⁺⁺ and G 7a) on each boat against a conventional destroyer employing guns and changes in course and speed. Using the probability of hitting the destroyer as a measure of effectiveness a spread angle of 0.5 degrees between the launched torpedoes is recommended as the optimal strategy.

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I. INTRODUCTION

Although wire-guided torpedoes have been introduced into the German Navy, many of the Fast Patrol Boats (FPB) must continue to use the older torpedoes, Mk 8⁺⁺ and G 7a, until 1974. These torpedoes have a direct influence on current tactics. Tactics such as single shots, open and closed formation, spread attack, etc. are presently in use. These tactics are not very suitable, however, against highly maneuverable ships such as a destroyer.

The most sophisticated current method of FPB attack is the sector attack. Because of its complexity and the difficulty in testing its effectiveness the sector attack has never been completely analyzed. The sector attack is, however, believed to be the most efficient, challenging and reliable attack tactic in use today. In an attempt to improve the sector attack, a computer model has been developed in this thesis in order to determine an optimal spread angle for a constant number of FPB against a single destroyer.

The measure of effectiveness employed in the use of the model is the probability of hitting the destroyer or, similarly, the number of torpedoes launched by the FPB. The analysis of the data involves maximizing the number of torpedoes launched while minimizing the number of FPB hit.

II. DESCRIPTION OF THE SECTOR ATTACK

The sector attack method has been accepted as one of the most effective means of attacking a highly maneuverable surface ship like a destroyer that, in addition to its evasive capabilities, employs an almost optimal offensive and defensive weapon system. The sector attack is primarily a function of the number and type of the attacking boats; the quantity and quality of the torpedoes employed; and, finally, the tactics employed. It is used in the following way:

A squadron of FPB on patrol proceed in close formation under radar silence. When a target has been detected on radar (intermittent sweeps) and identified as a hostile destroyer, the boats proceed to predetermined sectors. These sectors are a function of the number of boats involved and are determined prior to the attack. For example, with 10 boats, an angular difference of 36 degrees between the boats would define the sectors. The sector attack method requires that the attacking boats remain undiscovered while proceeding into their sectors. The boats are required, therefore, to stay outside the destroyer's maximum effective radar range which is also the maximum effective gunnery range. The objective is to launch a surprise attack against the destroyer. The time of the attack depends upon the time for the boat with the longest distance to reach its sector. Assuming all boats on STATION (on the perimeter of the maximum

effective radar range and in their sector) the times for starting the attack and releasing the torpedoes are transmitted by the Officer in Tactical Command (OTC). The time given by the OTC to proceed from the outer circle (initial STATION) to the inner circle (torpedo releasing point) is called the break-in phase.

The ensuing break-in phase is characterized by the prerequisite that each boat has to determine its course while proceeding at maximum speed in order to stay within the sector and to reach the torpedo releasing point within the given time period. Once the destroyer has detected the approaching boats it can be expected to make evasive maneuvers such as changes in course and speed and to employ its radar guided guns for defensive purposes. Each boat, therefore, will use completely different approach tactics. Boats with a high relative speed, for instance, start the break-in phase later in comparison to those with a small relative speed. To maintain coordination, if a boat leaves its sector it is imperative that it regains the original and predetermined sector whenever possible. The reason for this requirement is to deprive the destroyer of a vitally important degree of freedom in maneuvering arbitrarily and according to any arising favorable situation. At the time of torpedo launch all boats simultaneously fire their torpedo spread consisting of four or less torpedoes. The torpedo course is a function of bearing to the destroyer; speed of the torpedoes; and the course and speed of the destroyer

(transmitted by the OTC prior to the release of all torpedoes). Supplementary information concerning the sector attack is presented in Section III.A.

The immediate question of concern is what are the inherent factors that influence the effectiveness of the sector attack method. These factors are categorized as being of a technical or of a tactical nature.

Technical factors

Factors concerning the entire FPB torpedo weapon system:

1. The maximum speed of the boats during the break-in phase.
2. The design of the torpedo.
3. The torpedo firing system.
4. The silhouette of the approaching boats.

Tactical factors

Factors concerning the right attack procedures to be used:

1. The number of participating boats.
2. The number of torpedoes available.
3. The exact preservation of predetermined sectors.
4. The employment of zig-zag courses during the break-in phase.
5. The employment of radar decoys.
6. The time given by the OTC for the break-in phase.
7. The appropriate torpedo releasing point.
8. The spread angle for the torpedo spread.

Considering the technical factors an obvious improvement of the entire torpedo weapon system can be accomplished by an increase of the maximum speed, a better design of the torpedoes available, a better torpedo firing system that is independent of any rolling of the boat at the moment of firing and, finally, a small silhouette of the boat that decreases hostile radar capabilities.

Without changing the existing torpedo weapon system, the employment of an appropriate combination of tactical factors should facilitate an influence on the effectiveness of the torpedo weapon system:

An increase of the number of participating boats and, therefore, the number of torpedoes available, increases the probability of hitting the destroyer and, at the same time, decreases the probability of each boat being hit by the shells of the destroyer.

It is compulsory that each boat maintains its sector during the break-in phase in order to minimize the effect of destroyer maneuvers into unoccupied areas.

Boats with sufficient time during the break-in phase can make zig-zag courses in order to decrease the effectiveness of the radar guided guns. Since hitting the boats with shells is subject to chance, whatever the boats do, the employment of zig-zag courses remains questionable. The boats, therefore, take on course and speed of the destroyer in the case of excess of time.

The break-in phase is affected by the relative positioning of any boat with respect to the destroyer, the evasive

maneuvers and the employment of the guns of the destroyer. A general rule might be that large time restriction values imply a detrimental exposure to lethal destroyer shells while small values prevent some boats from reaching their torpedo releasing point. Both features stipulate success or failure of the mission.

The proper torpedo releasing point is primarily a function of the torpedo range. Since this range averages 3.5 nm (depending on the speed) the releasing point must be placed very close to the destroyer. In general, as the distance from the destroyer to the torpedo releasing point decreases the number of damaged boats can be expected to increase because of the amount of time the boats are in the gunnery range and the accuracy of the guns at short range. However, as the distance from the destroyer to the torpedo releasing point increases the number of torpedoes hitting the target can be expected to decrease because of the torpedo's limited range and capabilities.

The proper spread angle is the desired angle between the four torpedoes of a spread after being fired. A large angle does not necessarily imply a more efficient coverage of the area where the destroyer is expected to make evasive maneuvers. Many torpedoes are wasted. A very small angle facilitates a concentration at one place, thereby negating the possibility of extremely unexpected evasive maneuvers.

The relationship between these parameters and their interdependencies are the subject of this thesis. The

objective, therefore, is to search for an optimal combination of the time for the break-in phase, the appropriate torpedo releasing point and the spread angle. -

Since the sector attack is not necessarily restricted to a destroyer, an optimal combination should also be possible when the method is applied against merchant vessels, landing ships and even cruisers.

III. DESCRIPTION OF THE MODEL

A. INTRODUCTION

In order to find a reasonable combination of important tactical parameters that maximize the probability of hitting the destroyer a computer simulation model has been developed. This model is a detailed representation of the sector attack and utilizes Monte Carlo Techniques. The computer language used for the model was FORTRAN IV. The variables involved in the model are categorized as of a human or of a mechanical nature. These variables are represented by specific distributions and assumptions which are discussed later.

In the remainder of this section a thorough description of the model will be given: first in the form of a generalized flow chart (see Figure 1) and, secondly, in the form of a general treatment where the logical sequence of the corresponding steps are presented.

A representative FPB break-in phase is included in Appendix B.

The logical steps in the model are as follows:

1. The initial situation in the model is that all boats have reached their STATION. All boats are prepared to proceed at maximum speed in order to reach their final destination after a specified period of time.

2. During the break-in phase an almost perfect circular blip configuration of the approaching boats on the Planned Position Indicator (PPI) of the destroyer is maintained.

Initialize: Position all boats into their specified sectors at a specified distance to the destroyer

EVALUATION/DETERMINATION OF

1. course and speed changes of destroyer and corresponding times according to specific distributions
2. total number of hits all participating boats are exposed to
3. those boats which were hit and their degree of damage, i.e., speed reduction and torpedo, -tube damage and times of occurrence subject to specific assumptions
4. break-in times for the attacking boats and comparison of these to the times in 1. and 3.
5. final releasing point positions for all boats subject to the events in 1. through 4.

CALCULATION OF

1. course, speed and range for all remaining torpedoes subject to human and mechanical errors, where in addition the course is a function of the chosen spread angle
2. expected crossing points for destroyer and torpedo and determination of the probability of a hit subject to destroyer evasive measurements

Continuation by scrutinizing different spread angles for the torpedo spread, break-in times and torpedo releasing points.

Figure 1. GENERALIZED FLOW CHART.

All of the required course changes for the FPB are automatically processed in the model.

3. The destroyer is capable of destroying or damaging the approaching boats where the model determines continuous deterioration of FPB capabilities by deciding which boats, when and how many times they were hit and how badly they were damaged.

4. Each commanding officer of an FPB -- aware of the fact that damage to his boat might preclude a successful mission -- must adapt his break-in procedure to fast changing situations.

5. At the time of torpedo release all torpedo spreads are fired according to the individual data available at the moment. Course and speed of the destroyer is given by the OTC prior to the release.

6. The destroyer continues to make course and speed changes arbitrarily in order to evade the approaching torpedoes that run to their maximum range. Having succeeded in firing a remaining portion of the torpedoes, the boats proceed to their former initial STATION.

B. MODEL ASSUMPTIONS AND CONSTRAINTS

A set of necessary assumptions has been developed which insures the model to be as close as possible to real-world conditions while taking into account all arising problems.

1. Assumptions: Destroyer

a. Evasive maneuvers such as changes in course and speed are considered to be normally distributed.

b. Changes in course and speed are assumed to occur simultaneously in order to reduce computer time.

c. Changes in course are assumed to be linear which is justified for changes up to 60 degrees on either side because of the immense maneuverability of the destroyer.

d. Changes in speed are instantaneous changes with no delay.

e. The time for evasive maneuvers under attack is assumed to be exponentially distributed where the exchange ratio is the number of changes per 60 minutes (see Section III.D.).

f. The total number of shells launched is assumed to be binomially distributed. A normal approximation to the binomial distribution provides the necessary means to avoid time-consuming calculations (see Section III.D.).

g. The total number of possible hits on all boats is assumed to be a function of the product of the total number of shells being launched (see (f)) and the varying average hit probability of the shells.

h. The average hit probability of the shells is assumed to be an exponential function of the distance between initial and final STATION of the boats. (See Section III.D.)

i. The sector method entails a uniformly distributed target allocation for the destroyer guns.

j. The defense concentration and effort is more oriented to the closer targets. The square root of uniformly distributed random numbers times the time restriction is

assumed to represent appropriate time values concerning the hit on a boat.

2. Assumptions: Boats

a. The commanding officers of the boats are assumed to be experienced enough to immediately recognize on their radar screens any changing situation during the break-in phase and to react accordingly in order to keep the pre-determined sector and to decrease the distance with respect to the destroyer.

b. Once there is deviation from the proper bearing to the destroyer for any reason, the return into it is subject to estimating errors which are assumed to be normally distributed with a mean as a function of the lead angle and a standard deviation as a function of the mean.

c. The continuous deterioration of offensive capabilities (concerning speed and available torpedoes) as a result of one or more hits is assumed to occur according to the table presented at the end of this section. The speed values are subject to the failure of one, two or three engines, the availability of torpedoes is a function of the torpedo or torpedo tube destruction. Repairs are not possible.

d. Speed reductions according to the table are based on a uniform distribution.

e. The destruction of the torpedoes and torpedo tubes is based on a uniform distribution.

f. There does not exist any overkill capability as a result of more than one hit.

g. The reduction to speed 0 kn (i.e.: rudder hit) does not necessarily imply that the boat is out of action. The release of all torpedoes (unless already destroyed previously) is assumed to be still possible if the boat is in a favorable firing position.

h. In order to minimize computer running time, those boats with an excess of time available during the break-in phase do not perform zig-zag courses. They take on the course and speed of the destroyer.

i. The torpedo course is assumed to be normally distributed. It is subject to human and mechanical errors (incorrect course of the boat at the moment of launching the spread and insufficient functioning of the gyro compass or rudder device in the torpedo).

j. The speed of the torpedo is assumed to be normally distributed.

k. The range of the torpedo is assumed to be a function of its speed and air capacity needed for combustion. It is determined by a linear combination of maximum and minimum range/speed values.

3. Model Constraints: Destroyer

a. According to l.c. course changes up to 60 degrees are expected to be linear, larger deviations require a different model approach.

b. A steam-powered destroyer proceeding at 20 kn is restricted to an immediate speed range access of 11 to 29 kn. Different values from these are considered impossible.

c. The destroyer is assumed to be on a sortie.
Course changes of more than 60 degrees impair its mission.

d. The gunnery defense system is restricted to the employment of a gun of one type.

e. The guns cannot fire continuously because of technical problems.

4. Model Constraints: Boats

a. Boats which are farther away from the destroyer than a specified value (determined by OTC) at the moment of firing will not release torpedoes.

b. The model is restricted to night operations.

c. The employment of radar decoys during the break-in phase is excluded in this model.

d. The torpedo releasing point is restricted to distances more than 2.5 nm.

C. MODEL INPUT VARIABLES

The model has control over the following input variables:

1. Input Variables: Destroyer

a. The number of guns available for defense.

b. The number of shells that can be launched per gun and minute.

c. The maximum effective gunnery range which equals the maximum effective radar range.

d. The probability to successfully launch the shells.

- e. The probability to successfully hit the boats.
- f. The initial speed and speed deviation.
- g. The initial course and course deviation.
- h. The length of the destroyer.
- i. The rate of course and speed changes.

2. Input Variables: Boats

- a. The maximum speed.
- b. The torpedo speed.
- c. The minimum torpedo range for maximum permissible torpedo speed.
- d. The maximum torpedo range for minimum permissible torpedo speed.
- e. The maximum torpedo speed that can be adjusted.
- f. The minimum torpedo speed that can be adjusted.
- g. The torpedo course deviation caused by human errors.
- h. The torpedo course deviation caused by mechanical errors.
- i. The cease-fire value for boats too distant from the destroyer.
- j. The time restriction for the break-in phase.
- k. The spread angle.
- l. The predetermined torpedo spread releasing point.

A complete list of inputs including their required formats and abbreviations is included in Appendix C.

D. MODEL MATHEMATICS

The mathematics of the model is based on simple trigonometry using the law of SINES and COSINES. The calculations performed coincide with those in the real-world situation.

Sections (1) through (5) show the determination of unknown parameters as a function of known values.

Sections (6) through (8) show the necessary formulas for the realization of random variables according to specific distributions.

1. Determination of the Lead Angle

- a. for the break-in course of the boats and
- b. for the torpedo course.

Letting

VTARG = speed of the destroyer (stochastic),

VM = maximum speed of the boat (stochastic),

VTORP = speed of the torpedo (stochastic),

NC = the boat under consideration,

CORPEN = course of the destroyer (stochastic),

$X_1(NC)$ = distance between destroyer and boat before action,

$X_2(NC)$ = distance between destroyer and boat after action,

λ = angle between course of the destroyer and bearing to the boat in question,

δ = lead angle for boats and torpedoes.

These variables and their relationships are illustrated in Figure 2.

Applying the law of SINES, the following will be obtained for (a) and (b) above:

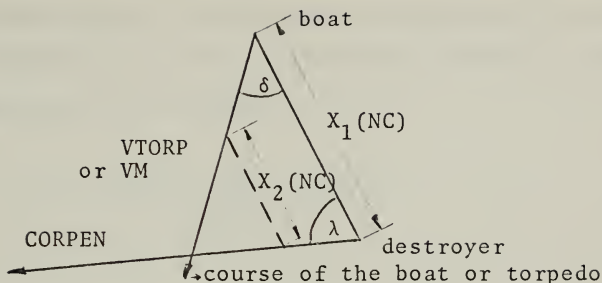


Figure 2.

$$\begin{aligned}
 \text{a. } \delta &= \sin^{-1} \left(\frac{VTARG}{VM} \sin \lambda \right) = \sin^{-1} (E(NC)) \\
 \text{b. } \delta &= \sin^{-1} \left(\frac{VTARG}{VTORP} \sin \lambda \right) .
 \end{aligned}$$

In the case that

$$(1) \quad VTARG \geq VM \quad \text{and} \quad \lambda \geq 90^\circ$$

or

$$(2) \quad E(NC) \geq 1.0,$$

then for (a) above:

$$\delta = 180.0 - \lambda,$$

i.e., (1) and (2) imply the impossibility of FPB remaining in their predetermined sector resulting in a change of the sector and an increase of the distance to the destroyer.

When

$$VTARG \leq VM \quad \text{or} \quad VTARG \leq VTORP$$

a misplacement is not possible.

2. Calculation of the Position for Misplaced Boats

If adverse circumstances force the boat to leave its sector (see 1.a.(1) and (2)), the boat proceeds with

the course and speed of the destroyer, increasing its distance and changing its sector by the value β which is calculated according to the formula

$$\beta = \sin^{-1} \left(\frac{X_3}{X_1(NC)} \sin \lambda \right),$$

where

X_1 = distance traveled by boat in Δt ,

X_2 = distance traveled by the destroyer in Δt ,

$X_3 = X_2 - X_1$.

The distance between destroyer and boat after Δt will be

$$X_2(NC) = \left(X_3^2 + X_1^2(NC) - 2 \cdot X_3 \cdot X_1(NC) \cdot \cos \lambda \right)^{0.5}$$

where

$$X_2(NC) \geq X_1(NC).$$

These variables are illustrated in Figure 3.

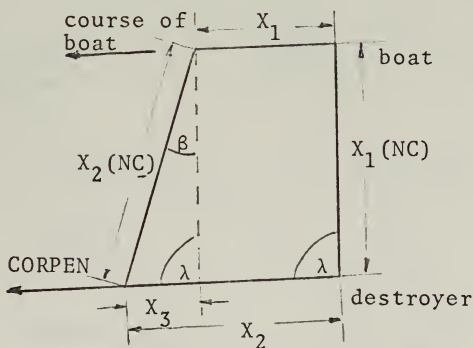


Figure 3.

3. Calculation for the Return into the Required Sector

In case the boat is misplaced, the return into the predetermined sector will be calculated in the following way:

$$V = \left(X_1^2 + X_1^2(\text{NC}) - 2 \cdot X_1 \cdot X_1(\text{NC}) \cdot \cos \gamma \right)^{0.5},$$

$$\eta = \sin^{-1} \left(\frac{X_1}{V} \sin \gamma \right)$$

$$\beta = \lambda_1 - \eta$$

$$X_2(\text{NC}) = \left(V^2 + X_2^2 - 2 \cdot V \cdot X_2 \cdot \cos \beta \right)^{0.5}$$

$$\lambda_2 = \sin^{-1} \left(\frac{V}{X_2(\text{NC})} \sin \beta \right).$$

The new sector can then be obtained by adding or subtracting λ_2 to or from the course of the destroyer. This is illustrated in Figure 4.

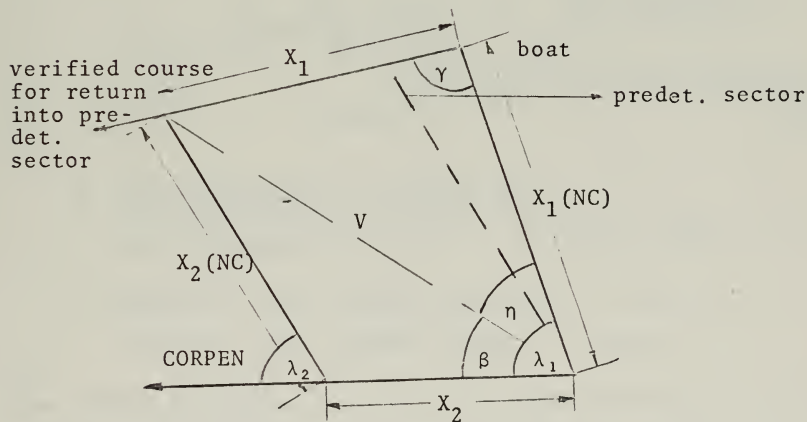


Figure 4.

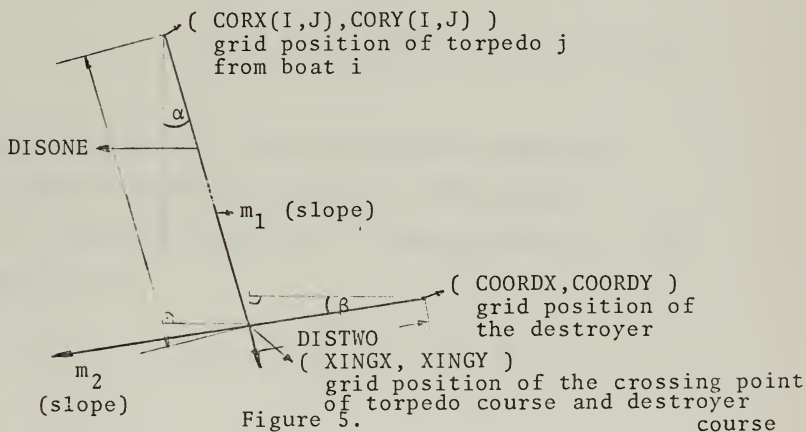
4. Determination of the Torpedo Crossing Point

The torpedo crossing point is determined in the following way:

$$\begin{aligned} \text{XINGX} = & (m_1 \cdot \text{CORX}(I,J) - m_2 \cdot \text{COORDX} + \text{COORDY} \\ & - \text{CORY}(I,J)) / (m_1 - m_2) \end{aligned}$$

$$\text{XINGY} = m_2 \cdot (\text{XINGX} - \text{COORDX}) + \text{COORDY}.$$

This is illustrated in Figure 5.



5. Determination of a Torpedo Hit

As illustrated in Figure 5, it follows that

$$\text{DISONE} = \text{ABS} (\text{XINGX} - \text{CORX}(I,J)) / \sin \alpha$$

$$\text{DISTWO} = \text{ABS} (\text{XINGX} - \text{COORDX}) / \cos \beta.$$

From DISONE the actual time of the torpedo crossing is computed. This time is used to compute DISTHR, the actual distance the destroyer travels up to the time of the torpedo

crossing. The following decision rule is then used to determine if the destroyer is hit:

$$0 \leq (\text{DISTHR} - \text{DISTWO}) \leq L \rightarrow \text{hit}$$

$$(\text{DISTHR} - \text{DISTWO}) > L \rightarrow \text{no hit}$$

$$(\text{DISTHR} - \text{DISTWO}) \leq 0 \rightarrow \text{no hit}$$

where L is the length of the destroyer.

6. The exponentially distributed time for evasive maneuvers is determined by:

$$t = \left(-\frac{1}{\lambda} \right) \ln(R) ,$$

where

R is a uniformly distributed random number and

λ equals the ratio of changes / 60 minutes.

7. Truncated normal (μ, σ^2) random numbers, R_N , are generated using

$$R_N = \sigma \cdot \left(\sum_{i=1}^{12} R_U - \frac{12}{2} \right) + \mu$$

where

R_U is a uniformly distributed random number.

8. The total number of hits on the boats is determined by:

$$\text{Letting } F_Y(x) = N_Z \left(\frac{x - np}{\sqrt{npq}} \right) = R,$$

then

$$\left(\frac{x - np}{\sqrt{npq}} \right) = N_Z^{-1} \left(F_Y(x) \right) = N_Z^{-1}(R)$$

and

$$x = np + N_Z^{-1} (F_Y(x)) (npq)^{0.5}$$

where

R = uniformly distributed random number,

n = (number of shells/60 minutes) \cdot time restriction,

p = launch probability of the shells,

$q = (1 - p)$,

X = total number of shells being launched.

Letting Z equal the number of possible hits, then

$$Z = X g ,$$

where

g equals the average hit probability of the shells.

TABLE I.

The following table shows the sequential deterioration of a boat that has suffered one or more hits:

$R \leq a$	Speed Reduction Down to: (kn)	Number of Possible Tor./-Tube Destructions
0.20	40	1
0.30	33	1
0.40	33	2
0.50	27	1
0.60	27	2
0.70	27	3
0.80	18	1
0.85	18	2
0.90	18	3
1.00	0	0

R is a uniformly distributed random number with the property that $R_{i+1} \geq R_i$.

IV. DESIGN AND TESTING PROCEDURE

A. DESIGN

Prior to the actual generation of data for analytical evaluation the computer program and its output were thoroughly checked by changing different input combinations continuously. The justification for the validity of the resulting data was based on common sense, experience and intuition.

Once the data were shown to be sufficiently reasonable, input variables were chosen for the ensuing analysis (see Table II) which were assumed to best represent the total sector attack. Many of the parameters were allowed to vary over a specified range, but the total number of participating boats, the length of the destroyer, the number of destroyer guns and the initial distance between destroyer and boats were assumed to be constant through all experiments.

The special parameters, their abbreviations and definitions and their possible and most likely ranges of interest are presented in Table III.

B. TESTING PROCEDURE

This section deals with the determination of the number of replications required to get sufficiently accurate values at a specified significance level and provides the description of the Analysis of Variance test applied to the generated data.

1. Determination of the Number of Replications

Assuming the average hit probability is normally distributed

$$\left(\text{PHIT} - \frac{a\sigma}{\sqrt{n}}, \text{PHIT} + \frac{a\sigma}{\sqrt{n}} \right)$$

is a confidence interval for the true mean value.

Choosing a confidence level of $\alpha = 0.05$

implies $a = 1.96$.

For $\sigma = 0.02$

and $L = 0.0045$

one gets

$$n = \left(\frac{2a\sigma}{L} \right)^2 = \left(\frac{3.92 \times 0.02}{0.0045} \right)^2 \approx 305.$$

Thus, 300 replications were chosen to provide a sufficiently accurate value at the specified significance level.

2. Two-way Analysis of Variance Test (ANOVA)

In order to investigate the sensitivity of the results due to different time restriction/releasing point / spread angle combinations an ANOVA test was chosen to yield the expected dependency or independency at a specified significance level α .

Letting X_{ij} , $i = 1, \dots, a$ (different TIMRES/DISTAN combinations)

$j = 1, \dots, b$ (different PSI values)

denote $n = a \cdot b$ random variables (means of hit probabilities) which are mutually stochastically independent and have normal

distributions with common variance σ^2 , the means of these normal distributions are

$$\mu_{ij} = \mu + \alpha_i + \beta_j$$

where

$$\sum_{i=1}^a \alpha_i = 0$$

and

$$\sum_{j=1}^b \beta_j = 0.$$

The following composite hypotheses were tested against all possible alternative hypotheses at a specified significance level α :¹

$$\text{CASE I:} \quad H_0: \beta_1 = \beta_2 = \dots = 0$$

$$\text{or } H_0: \mu_{ij} = \mu + \alpha_i \quad ; \quad \sum_i \alpha_i = 0$$

$$\text{against } H_1: \mu_{ij} = \mu + \alpha_i + \beta_j \quad ; \quad \sum_i \alpha_i = 0; \sum_j \beta_j = 0$$

$$\text{CASE II:} \quad H_0: \alpha_1 = \alpha_2 = \dots = 0$$

$$\text{or } H_0: \mu_{ij} = \mu + \beta_j \quad ; \quad \sum_j \beta_j = 0$$

$$\text{against } H_1: \mu_{ij} = \mu + \alpha_i + \beta_j \quad ; \quad \sum_i \alpha_i = 0; \sum_j \beta_j = 0.$$

The analysis for both cases is based on the ANOV - table presented as Table IV.

¹Hogg, R. V., Craig, A. T., Introduction to Mathematical Statistics, Section 10.6, 3 rd edition, The Macmillan Company, 1970

TABLE II. INPUT DATA
(Used for the analysis)

NA	=	10
NREPLI	=	300
NGNFRE	=	40
NRGUN	=	2
NU	=	15
IR	=	27345
IX	=	32529
EXCH	=	0.30
EFFGRM	=	8.00
GUNLAU	=	0.20
GUNIIT	=	0.10
VMAX	=	40.00
VTARG	=	20.00
SPDDEV	=	3.00
TGCRP	=	260.00
DELCOR	=	30.00
SLNGTH	=	400.00
VTORP ⁻	=	40.00
PSIINC	=	0.50
TORRMN	=	2.50
TORRMX	=	5.00
TORSMX	=	45.00
TORSMN	=	35.00
DEL	=	0.50

TORDEV = 0.50
THE = 0.10
DISSTP = 5.00
DISTAN = varies
TIMRES = varies
PSI = varies

TABLE III. PARAMETER RANGES

Abbreviation	Meaning	Possible Range	Most Likely Range
NGNFRE	Number of theoretical shots per gun and minute	35 - 45	40
GUNLAU	Launch probability for guns, including cooling effects and long firing times	0.0 - 1.0	0.1 - 0.3
GUNHIT	Hit probability for shells (for EEFGRM)	0.0 - 1.0	0.0 - 0.15
VTARG	Initial destroyer speed	0 - 35	11 - 29
TGCRP	Initial destroyer course	0 - 360	260
SPDDEV	Speed deviation	0 - 35	0 - 3
DELCOR	Course deviation	0 - 360	0 - 40
EXCH	Rate of course and speed changes	0 - 60	0 - 20
VMAX	Maximum FPB speed	39 - 42	40
VTORP	Torpedo speed	35,40,45	40
TORDEV	Torpedo speed deviation	0 - 5	2 - 3
DEL	Torpedo course deviation due to human errors	0 - 360	0 - 10
THE	Torpedo course deviation due to mechanical errors	0 - 360	0 - 10
DISSTP	Cease-fire value	2.5 - 8.0	4.5- 5.5
DISTAN	Torpedo releasing point	0.0 - 8.0	2.5- 4.0
TIMRES	Time restriction for break-in phase	0 - inf.	5.0-15.0
PSI	Spread Angle	0 - 180	0.0- 5.0

TABLE IV. ANALYSIS OF VARIANCE FOR TWO-WAY BALANCED CLASSIFICATION

Source	DF	SS	MS	F
Total	ab	$\sum_{ij} x_{ij}^2$		$\frac{b \sum_i (\bar{X}_{i.} - \bar{X})^2}{(a-1)}$
α -class	a-1	$\sum_i (\bar{X}_{i.} - \bar{X})^2$	s_1^2	$\frac{\sum_{ij} (X_{ij} - \bar{X}_{i.} - \bar{X}_{.j} + \bar{X})^2}{(a-1)(b-1)}$
β -class	b-1	$\sum_j (\bar{X}_{.j} - \bar{X})^2$	s_2^2	$\frac{a \sum_j (X_{.j} - \bar{X})^2}{(b-1)}$
Error	(a-1)(b-1)	$\sum_{ij} (X_{ij} - \bar{X}_{i.} - \bar{X}_{.j} + \bar{X})^2$	s_3^2	$\frac{\sum_{ij} (X_{ij} - \bar{X}_{i.} - \bar{X}_{.j} + \bar{X})^2}{(a-1)(b-1)}$

F has an F distribution with (b-1), (a-1)(b-1) df for CASE I and
(a-1), (a-1)(b-1) df for CASE II

at a specified significance level α .

V. DATA AND ANALYSIS

A. DATA

In the data presented the interrelationship of the tactical variables and their critical ranges were as follows:

Tactical Variable	Range
1. Spread Angle	0.0 - 2.5 degrees
2. Time Restriction	5.0 - 10.0 minutes
3. Torpedo Releasing Point	2.5 - 3.5 nm

The output data from the simulation have been tabulated and are contained in Table V. Based upon this data the following observations can be made:

1. Since the torpedo course is a function of the spread angle and errors, a spread angle of 0 degrees would provide an acceptable hit probability value over the total range of time restriction/ releasing point combinations. Because of technical infeasibility only multiples of 0.5 degrees can be realized within the torpedo system on board the FPB. The data indicate that in almost all experiments a maximum value of the probability of hitting the destroyer was obtained for a spread angle of 0.5 degrees. The more the spread angle increases the more the hit probability decreases, a statement that coincides with the intuitive inference about this behaviour.

2. Large time restriction values considerably impair the offensive capabilities of the attacking boats because

more boats are damaged or destroyed. This has a direct impact on the probability of hitting the destroyer because the total number of launched torpedoes decreases as the number of damaged boats increases. On the other hand, very small time restriction values will primarily prevent these damaged boats from reaching the required releasing point in time. The data show that the effect will be the same in comparison to large time restriction values. Values between 5 and 10 minutes reveal better hit probabilities within each releasing point group and for every spread angle column.

3. The total number of hits from the destroyer shells is in addition to (2) a function of the releasing point. Smaller distances from the destroyer increase the shell hit probability, an effect which is indicated by the data to be of more importance than that from different time restrictions. Although the number of attacking boats will be decreased in direct ratio to the releasing point distance, the overall hit probability will generally be increased. This is because every torpedo spread from those boats which reach the releasing point undamaged becomes more dangerous and, therefore, more efficient.

Considering (2) and (3) together a hit ratio value has been included in the program that shows the detrimental effects on all boats when different time restriction/ releasing point combinations are applied. The hit ratio, therefore, is defined to be the ratio of the sum of all hits on the boats and the total number of shells theoretically possible during

one experiment. Since this value increases considerably for increasing time restrictions or decreasing releasing points, the employment of a close releasing point should cause some thought for the decision maker.

B. ANALYSIS

In order to determine an optimal spread angle for all combinations of (2) and (3) in the last section and, additionally, to find the best releasing point and time restriction to maximize the probability of hitting the destroyer, an ANOV test (see Section IV.B) was applied to the data obtained at a specified significance level.

Seven different tests (a) through (g) were performed which were designed to show significantly different hit probabilities for various time restriction / releasing point / spread angle combinations.

With respect to the aforementioned testing procedure and the computer output, ANOV tables were constructed which deal with two cases, namely (see Table VI.):

CASE I: Tests (a), (b), (c) and (d) investigate the means for different spread angles and specified time restriction / releasing point combinations (β -classification).

CASE II: Tests (e), (f) and (g) investigate the means for different time restriction / releasing point combinations and specified spread angles (α -classification).

The investigation of CASE I results in the rejection of the Null Hypothesis that the means are equal, because with only one exception (for the releasing point of 3.5 nm in (c)) all test statistics are greater than the corresponding 95 percentage point of the F Distribution. This implies that there exists a significant difference in the means for all spread angles under consideration. Since the spread angle of 0.5 degrees shows an obvious accumulation of maximum hit probabilities for almost all time restriction / releasing point combinations, this value is considered to be optimal.

The investigation of CASE II was based on spread angles between 0.5 and 1.5 degrees. Keeping this range constant for all tests (e), (f) and (g) the comparison of the releasing points 3.5 and 3.0 nm in (e) and 3.0 and 2.5 in (f) for the time restriction values of 8.0, 7.0 and 6.0 minutes leads to the rejection of the Null Hypothesis that the means are equal at the specified significance level which implies that for different releasing points significantly different hit probabilities arise. Since the realization of the releasing point at 2.5 nm is difficult due to maneuvering restrictions and hardly acceptable because of a high hit ratio value the computer output shows maximum means for the releasing point at 3.0 nm.

Finally, test (g) in CASE II examines the significance of the means for the time restriction values 8.0, 7.0 and 6.0 for each releasing point group keeping the spread angles

constant. Except for the releasing point 2.5 nm the time restrictions under consideration do not give significantly different means. Restricting the analysis to the releasing point of 3.0 nm an optimal time restriction value of 7.0 minutes may be justified.

TABLE V. COMPUTER OUTPUT

			SPREAD ANGLE					
			0.000	0.500	1.000	1.500	2.000	2.500
TIMRES	DISTAN	HITRAT	HIT PROBABILITY					
10.0	3.5	0.0339	0.163	0.187	0.160	0.153	0.103	0.047
8.0	3.5	0.0335	0.180	0.210	0.197	0.150	0.107	0.053
7.0	3.5	0.0333	0.213	0.263	0.267	0.180	0.153	0.103
6.0	3.5	0.0332	0.263	0.330	0.260	0.187	0.147	0.100
5.0	3.5	0.0330	0.217	0.257	0.227	0.153	0.090	0.053
10.0	3.0	0.0364	0.180	0.210	0.217	0.220	0.163	0.117
8.0	3.0	0.0363	0.237	0.297	0.277	0.257	0.213	0.157
7.0	3.0	0.0358	0.267	0.313	0.287	0.253	0.180	0.117
6.0	3.0	0.0359	0.213	0.283	0.270	0.187	0.117	0.073
5.0	3.0	0.0354	0.230	0.273	0.230	0.153	0.120	0.087
10.0	2.5	0.0394	0.267	0.270	0.240	0.233	0.217	0.217
8.0	2.5	0.0392	0.233	0.333	0.287	0.273	0.217	0.187
7.0	2.5	0.0387	0.280	0.323	0.323	0.277	0.227	0.130
6.0	2.5	0.0387	0.240	0.300	0.260	0.240	0.157	0.127
5.0	2.5	0.0390	0.207	0.280	0.273	0.177	0.113	0.080

TABLE VI. ANOV TABLE CASE I (a)

$$H_0: \mu_{ij} = \mu + \alpha_i \quad ; \quad \sum_i \alpha_i = 0$$

$$H_1: \mu_{ij} = \mu + \alpha_i + \beta_j \quad ; \quad \sum_i \alpha_i = 0, \quad \sum_j \beta_j = 0$$

for TIMRES = 10.0, 8.0, 7.0, 6.0, 5.0 (a=1,...,5)

PSI = 0.0,.....,2.5 (b=1,...,6)

Investigate group (1) with DISTAN = 3.5

(2) with DISTAN = 3.0

(3) with DISTAN = 2.5

Source	DF	SS	MS	F
(1)		1.03891		
Total (2)	20	1.39931		
(3)		1.74645		
(1)		0.00429	0.00107	
α -class (2)	4	0.00312	0.00078	
(3)		0.00340	0.00085	
(1)		0.02267	0.00453	57.37129*
β -class (2)	5	0.01913	0.00383	29.81146*
(3)		0.01614	0.00323	18.41306*
(1)		0.00790	0.00040	
Error (2)	20	0.01283	0.00064	
(3)		0.01753	0.00088	

For $\alpha = 0.05$ which implies $F_{5,20}(\alpha) = 2.71$ all Null Hypotheses will be rejected.

TABLE VI. ANOV TABLE CASE I (b)

$$H_0: \mu_{ij} = \mu + \alpha_i \quad ; \quad \sum_i \alpha_i = 0$$

$$H_1: \mu_{ij} = \mu + \alpha_i + \beta_j \quad ; \quad \sum_i \alpha_i = 0, \sum_j \beta_j = 0$$

for TIMRES = 8.0, 7.0, 6.0 (a=2,.....,4)

PSI = 0.0,....., 1.5 (b=1,.....,4)

Investigate group (1) with DISTAN = 3.5

(2) with DISTAN = 3.0

(3) with DISTAN = 2.5

Source	DF	SS	MS	F
(1)		0.63667		
Total (2)	12	0.82624		
(3)		0.95866		
(1)		0.00292	0.00146	
α -class (2)	2	0.00088	0.00044	
(3)		0.00084	0.00042	
(1)		0.00490	0.00163	10.51679*
β -class (2)	3	0.00336	0.00112	21.85428*
(3)		0.00271	0.00090	11.99105*
(1)		0.00280	0.00047	
Error (2)	6	0.00092	0.00015	
(3)		0.00136	0.00023	

For $\alpha = 0.05$ which implies $F_{3,6}(\alpha) = 4.76$ all Null Hypotheses will be rejected.

TABLE VI. ANOV TABLE CASE I (c)

$$H_0: \mu_{ij} = \mu + \alpha_i \quad ; \quad \sum_i \alpha_i = 0$$

$$H_1: \mu_{ij} = \mu + \alpha_i + \beta_j \quad ; \quad \sum_i \alpha_i = 0, \quad \sum_j \beta_j = 0$$

for TIMRES = 8.0, 7.0, 6.0 (a = 2, ..., 4)

PSI = 0.0, 0.5, 1.0 (b = 1, ..., 3)

Investigate group (1) with DISTAN = 3.5

(2) with DISTAN = 3.0

(3) with DISTAN = 2.5

Source	DF	SS	MS	F
(1)		0.54680		
Total (2)	9	0.67109		
(3)		0.74980		
(1)		0.00398	0.00199	
α -class (2)	2	0.00056	0.00028	
(3)		0.00088	0.00044	
(1)		0.00120	0.00060	4.03655
β -class (2)	2	0.00178	0.00089	30.24245*
(3)		0.00231	0.00115	11.64811*
(1)		0.00179	0.00045	
Error (2)	4	0.00035	0.00009	
(3)		0.00119	0.00030	

For $\alpha = 0.05$ which implies $F_{2,4}(\alpha) = 6.94$ the Null Hypotheses will be rejected for DISTAN = 3.0 and 2.5. For DISTAN = 3.5 it will be accepted.

TABLE VI. ANOV TABLE CASE I (d)

$$H_0: \mu_{ij} = \mu + \alpha_i \quad ; \quad \sum_i \alpha_i = 0$$

$$H_1: \mu_{ij} = \mu + \alpha_i + \beta_j \quad ; \quad \sum_i \alpha_i = 0, \quad \sum_j \beta_j = 0$$

for TIMRES = 8.0, 7.0, 6.0 (a= 2,.....,4)

PSI = 0.5, 1.0, 1.5 (b= 2,.....,4)

Investigate group (1) with DISTAN = 3.5

(2) with DISTAN = 3.0

(3) with DISTAN = 2.5

Source	DF	SS	MS	F
(1)		0.48974		
Total (2)	9	0.65341		
(3)		0.76837		
(1)		0.00282	0.00141	
α -class (2)	2	0.00072	0.00036	
(3)		0.00092	0.00046	
(1)		0.00486	0.00242	11.63224*
β -class (2)	2	0.00277	0.00138	20.97191*
(3)		0.00151	0.00077	14.06532*
(1)		0.00250	0.00063	
Error (2)	4	0.00079	0.00020	
(3)		0.00065	0.00016	

For $\alpha = 0.05$ which implies $F_{2,4}(\alpha) = 6.94$ all Null Hypotheses will be rejected.

TABLE VI. ANOV TABLE CASE II (e), (f)

$$H_0: \mu_{ij} = \mu + \beta_j \quad \sum_j \beta_j = 0$$

$$H_1: \mu_{ij} = \mu + \alpha_i + \beta_j ; \quad \sum_i \alpha_i = 0, \quad \sum_j \beta_j = 0$$

for TIMRES = 8.0, 7.0, 6.0 and DISTAN = 3.5/3.0 (a=1,...,6)
 (e) PSI = 0.5, 1.0, 1.5 (b=1,...,4)

Investigate the means for different DISTAN values

Source	DF	SS	MS	F
Total	18	1.14315		
α -class	5	0.00595	0.00119	9.58205*
β -class	2	0.00374	0.00187	
Error	10	0.00373	0.00037	

For $\alpha = 0.05$ which implies $F_{5,10}(\alpha) = 3.33$ the
 Null Hypotheses is rejected

for TIMRES = 8.0, 7.0, 6.0 and DISTAN = 3.0/2.5 (a=1,...,6)
 (f) PSI = 0.5, 1.0, 1.5 (b=2,...,4)

Investigate the means for different DISTAN values

Source	DF	SS	MS	F
Total	18	1.42178		
α -class	5	0.00245	0.00049	7.58616*
β -class	2	0.00207	0.00103	
Error	10	0.00195	0.00020	

For $\alpha = 0.05$ which implies $F_{5,10}(\alpha) = 3.33$ the
 Null Hypothesis will be rejected

TABLE VI. ANOV TABLE CASE II (g)

$$H_0: \mu_{ij} = \mu + \beta_j \quad ; \quad \sum_j \beta_j = 0$$

$$H_1: \mu_{ij} = \mu + \alpha_i + \beta_j \quad ; \quad \sum_i \alpha_i = 0, \quad \sum_j \beta_j = 0$$

for TIMRES = 8.0, 7.0, 6.0 (a = 1, ..., 3)

PSI = 0.5, 1.0, 1.5 (b = 2, ..., 4)

Investigate group (1) with DISTAN = 3.5

(2) with DISTAN = 3.0

(3) with DISTAN = 2.5

Source	DF	SS	MS	F
(1)		0.48974		
Total (2)	9	0.65341		
(3)		0.76837		
(1)		0.00282	0.00141	6.781
α -class (2)	2	0.00072	0.00036	5.489
(3)		0.00092	0.00046	8.394*
(1)		0.00485	0.00242	
β -class (2)	2	0.00277	0.00138	
(3)		0.00153	0.00077	
(1)		0.00250	0.00063	
Error (2)	4	0.00079	0.00020	
(3)		0.00065	0.00016	

For $\alpha = 0.05$ which implies $F_{2,4}(\alpha) = 6.94$ the Null Hypotheses will be accepted except for DISTAN = 2.5.

VI. CONCLUSIONS AND RECOMMENDATIONS

The results obtained can be summarized in the following way:

1. Significant differences in the hit probability are observed as a function of changes in

- a. the spread angle,
- b. the releasing point, and
- c. the time restriction considerably different

from 7 minutes.

2. The optimal spread angle is significantly dependent on the correct torpedo courses within the torpedo spread. Deviations (caused by human and mechanical insufficiencies) up to two degrees from the calculated torpedo course imply an optimal spread angle down to 0.05 degrees which cannot be realized because of technical infeasibility. Careful attention should be paid to these errors which should be kept at a minimum.

3. The simulation of the use of radar decoys during the break-in phase by decreasing the hit probability of the destroyer shells shows a considerable increase of the probability of hitting the destroyer and results in the same choice of the optimal tactical variables combination proposed. (The utilization of radar decoys, though, was not a subject of the analysis).

4. Boats being further away than 5.5 nm from the destroyer at the moment of torpedo release do not contribute

anything to success or failure of the mission, though their participation is necessary for deceiving purposes. The OTC has to decide whether the torpedoes are to be fired or not. The computer model was developed primarily to determine an optimal solution subject to a specific set of assumptions. The random variables applied in this model were chosen to be as close as possible to the real-world situation. The generated data reveals satisfactory insight into the interdependencies of all values involved.

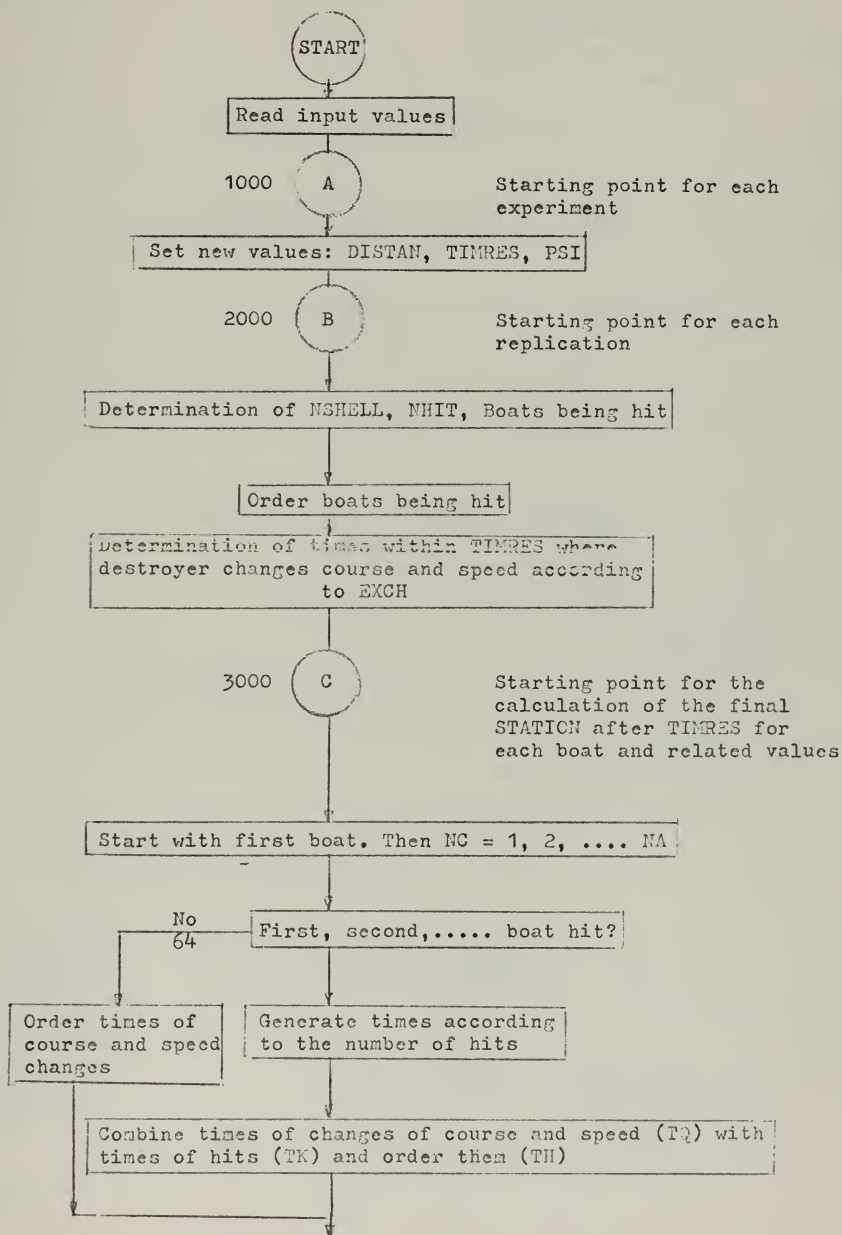
Since the computer running time for the model would be increased considerably when scrutinizing the interrelationship of all random variables involved, the emphasis was placed primarily on vital factors which made it possible to draw reasonable and credible conclusions.

The recommendations for a successful sector attack can be summarized in the following way:

The utilization of a spread angle/ time restriction/ releasing point combination of 0.5 degrees/ 7 minutes/ 3.0 nm will yield an optimal hit probability against an ordinary destroyer assuming no major hardware changes possible for the torpedo weapon system in question.

The effectiveness can be improved up to 50% by employing the recommended spread angle in comparison to the data obtained from the currently used angle of 1.5 degrees.

APPENDIX A. FLOW CHART



70

80



Starting point for each calculation of the STATION of the boat with respect to different TH values

Calculate XLAMBD, XDELTA, E, T

((VM=0.0) and (TH > TIMRES))

Yes

136

No

VM=0.0

Yes

128

No



(TH > TIMRES and boat on STATION)

Yes

136

No



H

((VTARG ≥ VM) and (XLAMBD ≥ 90))

Yes

100

No

E ≥ 1.0

Yes

100

No

Boat takes on destroyer course and speed. New XDELTA, T

E

Yes

125

TH ≥ TIMRES

No



Yes

125

TH ≥ TIMRES

No

G

Yes

109

Boat proceeds on parallel destroyer course ?

No

Calculate
TE=TH(NG)-TH(NG-1)

Calculate X and new sector

120

Calculate TE=TH(NG)-TH(NG-1)
TB=TIMRES-TH(NG-1)

T ≥ TB

Yes

107

No

Calculate next distance to destroyer

T ≥ TIMRES-TH(NG)

Yes

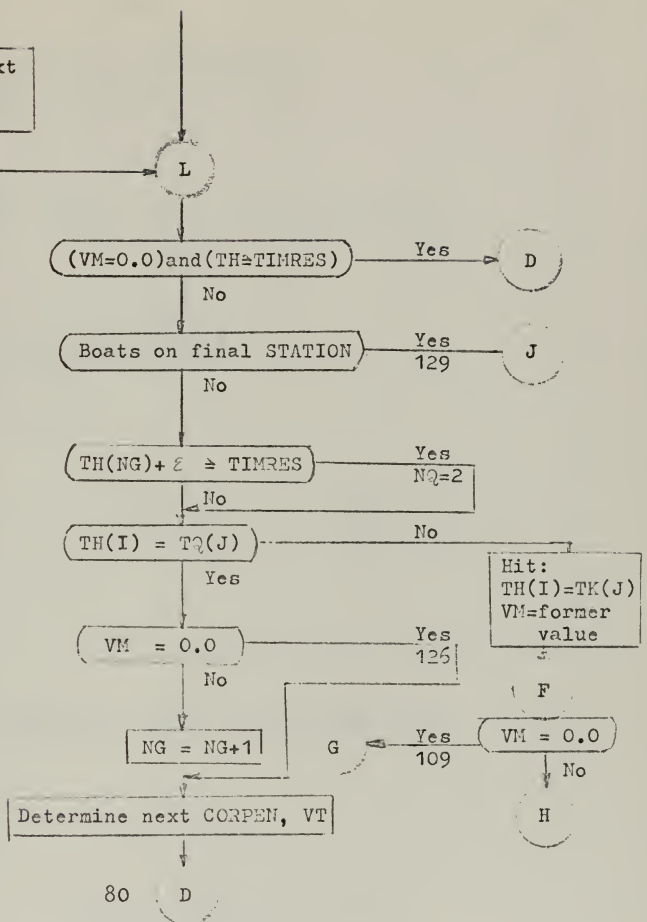
105

No

250

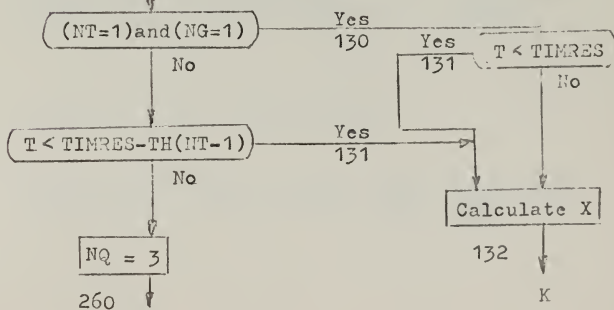
250

Calculate next
distance to
destroyer



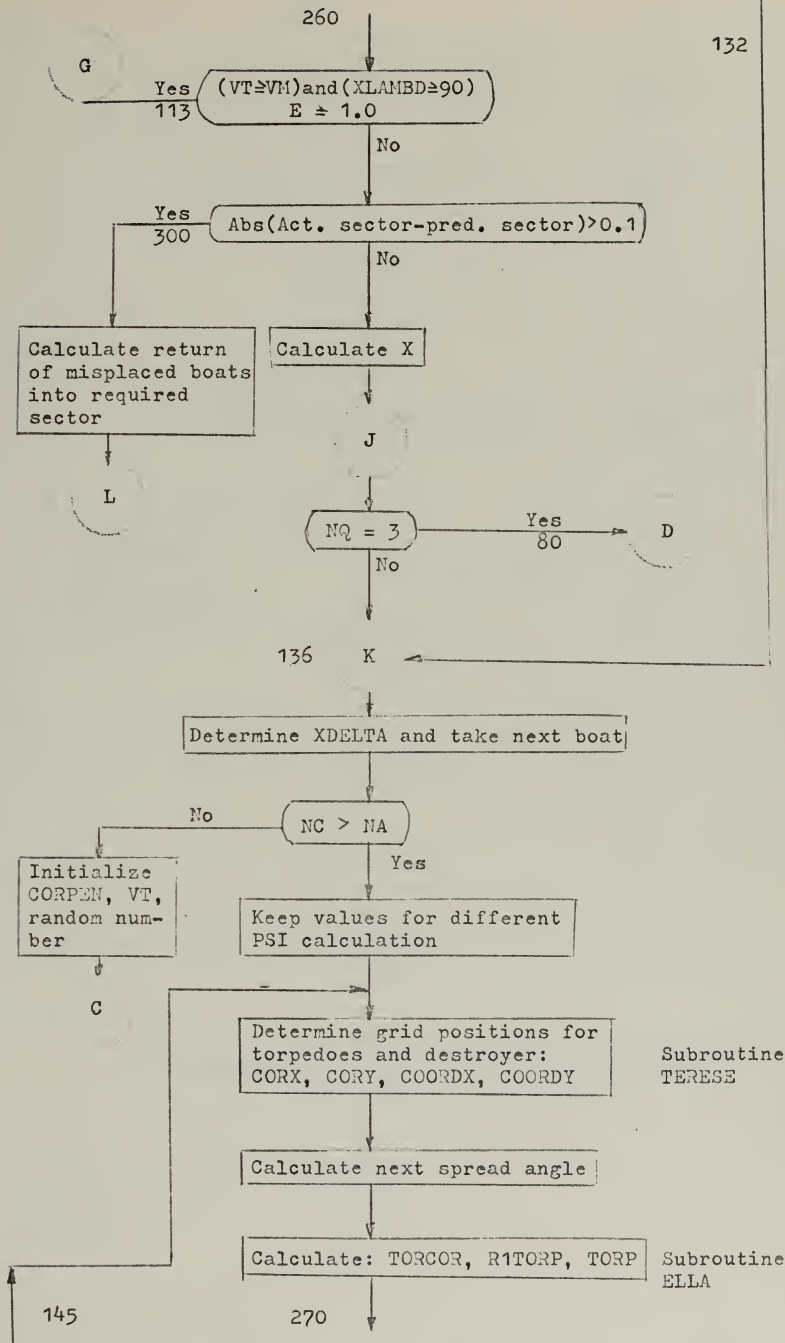
80

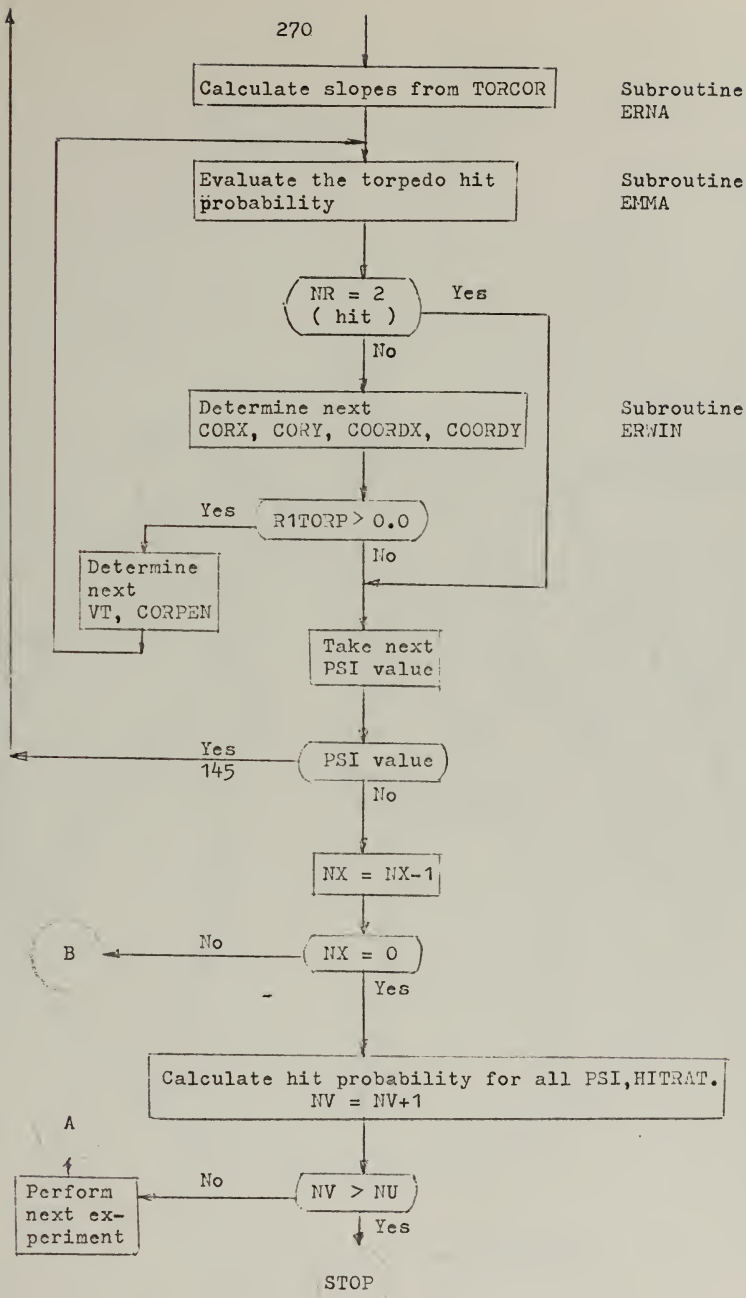
125



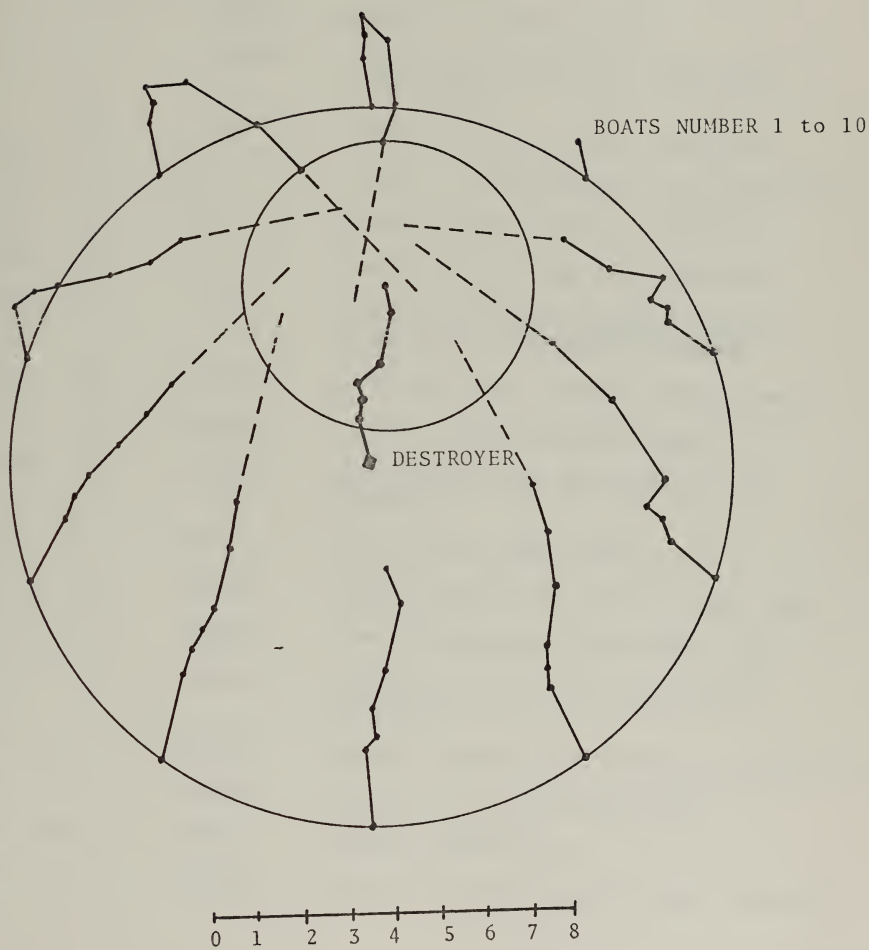
260

50





APPENDIX B: DRAWING



APPENDIX C: INPUT CARDS

First Card

Column	Abbrev.	Meaning
1 - 2	NA	Number of Fast Patrol Boats
3 - 6	NREPLI	Number of replications
7 - 9	NGNFRE	Number of theoretical shots/gun and minute
10	NRGUN	Number of guns on the destroyer
11 - 12	NU	Number of experiments to be performed
13 - 17	IR	Random number (up to 5 digits)
18 - 22	IX	Random number (up to 5 digits)
23 - 26	EXCH	Rate of course and speed changes (number of changes/60 minutes)
27 - 29	EFFGRM	Effective max. gunnery range (nm)
30 - 33	GUNLAU	Launch probability for guns
34 - 37	GUNHIT	Hit probability for shells (for EEFGRM)
38 - 41	VMAX	Maximum FPB speed (kn)
42 - 45	VTARG	Initial speed of the destroyer (kn)
46 - 48	SPDDEV	Speed deviation of destroyer (kn)
49 - 53	TGCORP	Initial course of the destroyer (degrees)
54 - 57	DELCOR	Course deviation of destroyer (degrees)
58 - 62	SLNGTH	Length of the destroyer (ft)
63 - 66	VTORP	Torpedo speed (kn)
67 - 70	PSIINC	Increase of the spread angle (degrees)

Second Card

Column	Abbrev.	Meaning
1 - 3	TORRMN	Minimum torpedo range (nm)
4 - 6	TORRMX	Maximum torpedo range (nm)
7 - 10	TORSMX	Maximum torpedo speed (kn)
11 - 14	TORSMN	Minimum torpedo speed (kn)
15 - 17	DEL	Torpedo course deviation caused by human errors (degrees)
18 - 20	TORDEV	Torpedo speed deviation (kn)
21 - 24	THE	Torpedo course deviation caused by mechanical errors (degrees)
25 - 27	DISSTP	Cease-fire value for boats which are not on STATION (nm)

Third Card

1 - 3	DISTAN	Predetermined closest distance to the destroyer at the moment of firing (nm)
4 - 7	TIMRES	Time restriction for the break-in phase (minutes)
8 - 11	PSI	First spread angle in question (degrees)

APPENDIX D: COMPUTER PROGRAM

General remarks remain to be made with respect to the development of the computer program and its logic involved.

Additional information will be given about the different subroutines applied in the program. Referring to what has already been said in Chapters II and III, the flow chart in Appendix A gives an additional insight into all the complexities involved.

In order to be able to determine the final STATION for each boat subject to destroyer changes in course and speed, hits by guns, time restriction, etc., the entire sector attack was decomposed into piecemeal operations. Furthermore, most of the time values are completely different for every boat and it was decided to treat every boat separately and sequentially up to the point where all boats have to release their torpedo spread simultaneously. This procedure simplified the logic considerably.

After the initial phase the program continues to determine the total number of possible hits all boats are exposed to by utilizing Subroutine EMIL in connection with Subroutine TANTE which is a uniform random number generator.

After it is determined which boats have suffered one or more hits, Subroutine EGON in connection with Subroutine TANTE and Subroutine TINA determines speed reduction and torpedo tube damage. The next operation deals with the different time values. Since the times for destroyer changes

in course and speed are all the same, they are calculated prior to the individual evaluation of all inherent time values due to the number of hits. The logic continues by first ordering these time values obtained for each boat individually and pursues one boat after the other to its final STATION. The required positions for misplaced boats (boats which had difficulties to remain in their predetermined sector) are reevaluated by Subroutine TILDA.

Having reached a specific STATION (subject to the above-mentioned fatalities and inconveniences), the boats are given the final data such as course and speed of the destroyer on which the lead angle for the course determination of the torpedoes is based. From there, each released torpedo is transferred into a grid system which provides a more sufficient means for the calculation of the hit probabilities. In order to consider human error, as well as mechanical error, within the torpedo, Subroutine ELLA has been developed which determines the actual torpedo course, range and speed. Subroutine EMMA, in connection with Subroutine ERNA, considers both the destroyer and the torpedoes within the time period in question. In case the time to the next change in course and speed is greater than the time the torpedoes can run (as determined by Subroutine ELLA) Subroutine EMMA continues in calculating a possible torpedo hit by evaluating distances traveled by torpedoes and destroyers, calculating crossing points and comparing distance differences with the length of the destroyer. In case the torpedo

hits, the model continues immediately with the next PSI value or replication. In the event the above-mentioned time was less, the position of all torpedoes and the destroyer is recalculated by Subroutine ERWIN which, additionally, neglects those torpedoes which were running out of time and were, therefore, in excess of their range. This procedure is repeated for every spread angle in question before the next replication starts, generating a new set of final FPB STATIONS.

Once the final FPB STATIONS have been generated, the hit probabilities for all six spread angles are determined. The average ratio between the actual number of hits and the total number of shells available to which the boats could have been exposed, considering an absolutely perfect weapon system, serves as a decision variable with respect to the employment of a specific time restriction / releasing point strategy. The model continues in the same pattern by using different time restriction / releasing point combinations by keeping all the other input values constant.

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EVALUATION OF AN OPTIMAL SPREAD ANGLE FOR A COMBINED
EAST-PATPOL-BOAT SECTOR ATTACK WITH TORPEDOES
AGAINST ONE DESTROYED.

DIMENSION A(10),R(10),C(10),E(10),T(10),X(10),
1NK(10),NY(10),TG(10,10),TH(30),TK(15),TQ(15),
2SEC(10),SECI(10),SECINC(10),ASEC(10),
3XLAMPD(10),XMNLA(10),XDELTA(10),RXTHT(10,4),
4CORX(10),CORRY(10),CORX(10,4),CORY(10,4),
5SLUSIN(10,4),SLTCOS(10,4),TANCT(10,4),
6GRITOP(10,4),TORCOR(10,4),TORP(10,4),
7VWVW(10,10),VRAT(10),ZPSI(4),SUMHIT(6),PHIT(6)

DATA SECINC/0.0,0.0,120.0,90.0,72.0,60.0,51.42858,45.0,40.0,
136.0/ ,

PEAD(5,1) NA,NREPLI,NGNPE,NPGUN,NU,IR,IX,EXCH,EFFGRM,GUNLAU,
1GUNHIT,VMAX,VTARG,SDDDEV,TGCCOR,DELCOR,SLNGTH,VTORP,PSIINC

READ(5,2) TCRRMN,TCRRMX,TORSMX,TORSMN,DEL,TORDEV,THE,DISSTP
READ(5,3) DISTAN,TIMRES,PSI

INITIALIZE

PI=3.1415926536
MF=12493
KR=8*MF+3
TLNGTH=SLNGTH/6080.1
DEGRAD=PI/180.0
VMAX=VMAX/60.0
VTORP=VTORP/60.0
VTARG=VTARG/60.0
SDDDEV=SDDDEV/60.0
DEL=DEL*DEGRAD
TORDEV=TORDEV/60.0
TCRSMX=TCRSMX/60.0
TORSMN=TORSMN/60.0
XX=(TCRRAN-TORRMX)/(TORSMX-TCRSMN)
NX=NREPLI
NV=1
IU=IP
IV=IX
WRITE(6,9000) NREPLI,EXCH,GUNLAU,GUNHIT,VTARG,SDDDEV
WRITE(6,9004) TGCCOR,DELCOR,PSIINC,DISSTP
WRITE(6,9003)

```



```

X(I)=PSI
DO 7 I=1,6
X(I+1)=X(I)+PSI*INC
7 CONTINUE
WRITE(6,9001) (X(I),I=1,6)
WRITE(6,9005)

C
C 1000
DO 4 I=1,6
SUMMIT(I)=0.0
4 CONTINUE
APSI=PSI
NHIT2=0

C
C 2000
VT=VTARG
CORPEN=IGCORP
NSHELL=0
CNGRAX=10.0
CNGRDY=10.0
NR=1

C
DO 5 I=1,NA
X(I)=EFFGRM
DO 6 J=1,10
VMM(I,J)=VMAX
6 CONTINUE
5 SEC(I)=0.5*SECINC(NA)
SEC(1)=SEC(1)
DO 10 I=2,NA
SEC(I)=SEC(I-1)+SECINC(NA)
10 SEC(I)=SEC(I)
CONTINUE

C
C 16 I=1,NRGUN
SUBROUTINE TANTE GENERATES UNIFORMLY DISTRIBUTED
RANDOM NUMBERS
CALL TANTE (IX,IY,R)
SUBROUTINE EMIL IS USED FOR THE DETERMINATION OF THE ACTUAL
NUMBER OF SHELLS THE BOATS ARE EXPOSED TO
CALL EMIL (R,AX,D,IE)
NY(I)=NGNFRP*TIMRES*GUNLAU+AX*(NGNFR*TIMRES*GUNLAU*(1.0-GUNLAU))
1**0.5

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NSHELL=NSHELL+NY(I)
CONTINUE
16 NHIT=NSHELL*GUNHIT*(1.0+EXP(0.2*(8.0-DISTAN)))/2.0
NHIT2=NHIT*2+NHIT
DO 17 J=1,NHIT
CALL TANTE (IX,IY,R)
NK(J)=R*NA+0.5
IF(NK(J).EQ.0) NK(J)=1
17 CONTINUE
NHIT1=NHIT-1
DO 25 J=1,NHIT1
IW=I+1
DO 26 J=IW,NHIT
IF(NK(I).LE.NK(J)) GO TO 26
ITEMP=NK(I)
NK(I)=NK(J)
NK(J)=ITEMP
CONTINUE
26 CONTINUE
DO 30 I=1,NA
DO 28 J=1,4
TORP(I,J)=VTORP
29 CONTINUE
30 CONTINUE

SUBROUTINE EGON DETERMINES SPEED-REDUCTION AND TORPEDO-
TUBE-DAMAGE AFTER BEING HIT BY DESTROYER-SHELL
CALL EGON (IX,KA,NA,NHIT,NK,TORP,VMM)

TA=0.0
NR=1
60 IR=IR+KR
P=0.5+FLOAT(IR)*2.328306E-10
T(NP)=(-1.0/EXCH)*ALOG(R)+TA
TA=TQ(NB)
IF(TA.GT.TIMRES) GO TO 61
NR=NR+1
GO TO 60

61 NC=1
IW=IR
NN=1
3000 NC=0
VV=VMAX
62 IF(NK(NN).EQ.NC) GO TO 63

```



```

63 GO TO 64
   CALL TANTE (IX,IY,R )
   ND=ND+1
   TK(ND)=TIMPES*R*0.5
   NN=NN+1
   IF (NN.GT.NHIT) GO TO 64
   GO TO 62
64 NT=NF+ND
   DO 65 I=1,NB
   TH(I)=TQ(I)
65 CONTINUE
   NF=NF+1
   IF (ND.EQ.0) GO TO 70
   DO 67 I=NF,NT
   TH(I)=TK(I-NB)
67 CONTINUE
   NN1=NT-1
   IF (NN1.EQ.0) GO TO 70
   DO 68 I=1,NN1
   NN2=I+1
   DO 69 J=NN2,NT
   IF (TH(I).LE.TH(J)) GO TO 69
   TH(I)=TH(J)
   TH(J)=TH(I)
   TP(J)=TEMP
69 CONTINUE
68 CONTINUE

70 NG=1
   NH=1
   NQ=1

80 IF (ABS (SECI(NC)-CORPEN).GT.180.0) GO TO 85
   GO TO 95
85 IF (CORPEN.LT.SECI(NC)) GO TO 90
   SECI(NC)=SECI(NC)+360.0
   GO TO 95
90 CORPEN=CORPEN+360.0
   XLAMBD(NC)=ABS (SECI (NC)-CORPEN)
   IF (SECI (NC).GE.360.0) SECI (NC)=SECI (NC)-360.0
   IF (CORPEN.GT.360.0) CORPEN=CORPEN-360.0
   IF (XLAMBD(NC).EQ.0.0) XLAMBD(NC)=1.0E-10
   IF (XLAMBD(NC).EQ.180.0) XLAMBD(NC)=1.0E-10
   X*NLAM(NC)=XLAMBD(NC)*DEGRAD
   A(NC)=SIN (X*NLAM(NC))
   IF (V*.EQ.1.0E-10.AND.NQ.EQ.2) GO TO 136

```

CC

CC


```

IF(VM.EQ.1.0F-10) GO TO 128
IF(NQ.EQ.3) GO TO 136
VRAT(NC)=VT/VM
R(NC)=(X(NC)-DISTAN)/VM
E(NC)=VRAT(NC)*A(NC)
IF(VI.GE.VM.AND.XLAMBD(NC).GE.90.0) GO TO 100
IF(E(NC).GE.1.0) GO TO 100
XDELTA(NC)=ARSIN(E(NC))
C(NC)=SIN(XDELTA(NC)+XMNLAM(NC))
T(NC)=R(NC)*A(NC)/C(NC)
IF(NQ.EQ.2) GO TO 125
IF(ABS(SEC1(NC)-SEC(NC)).GT.0.1) GO TO 300
GO TO 101

C 100 XDELTA(NC)=(180.0-XLAMBD(NC))*DEGRAD
C(NC)=SIN(XDELTA(NC)+XMNLAM(NC))
T(NC)=100.0
IF(NQ.EQ.2) GO TO 125

C 101 IF(TH(NG).GE.TIMRES) GO TO 125
IF(T(NC).EQ.100.0) GO TO 109
IF(NQ.EQ.1) GO TO 102
TE=TH(NG)-TH(NG-1)
TR=TIMRES-TH(NG-1)
GO TO 103
102 TB=TIMRES
TE=TH(NG)
103 IF(T(NC).GE.TR) GO TO 107
IF(T(NC).GE.(TIMRES-TH(NG))) GO TO 105
GO TO 120
105 X(NC)=X(NC)-VM*(T(NC)-(TIMRES-TH(NG)))*C(NC)/A(NC)
GO TO 120
107 X(NC)=X(NC)-VM*TE*C(NC)/A(NC)
GO TO 120
109 IF(NQ.EQ.1) GO TO 111
TE=TH(NG)-TH(NG-1)
GO TO 113
111 TE=TH(NG)
113 IF(NQ.EQ.3) TE=TIMRES-TH(NT-1)
IF(VM.EQ.1.0E-10.AND.NQ.EQ.2) TE=TIMRES-TH(NT-1)
X1=VM*TE
X2=VT*TE
X3=X2-X1
X(NC)=(X3**2+X(NC)**2-2.0*X3*X(NC)*COS(XMNLAM(NC)))*.5
RETA=ARSIN((X3/X(NC))*SIN(XMNLAM(NC)))/DEGRAD
IF(CORPEN.GE.180.0) GO TO 117
IF(SEC1(NC).LT.CORPEN.OP.SEC1(NC).GT.(CORPEN+180.0)) GO TO 115

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      SECL(NC)=SECL(NC)+BETA
      GO TO 120
115  SECL(NC)=SECL(NC)-BETA
      GO TO 120
117  IF (SECL(NC).GT.CORPEN.OR.SECL(NC).LT.(CORPEN-180.0)) GO TO 119
      SECL(NC)=SECL(NC)-BETA
      GO TO 120
119  SECL(NC)=SECL(NC)+BETA
      C
      C
      C
120  IF (VM.EQ.1.0E-10.AND.NQ.EQ.2) GO TO 80
      IF (NQ.EQ.3) GO TO 129
      IF (NG.EQ.(NT-1)) NQ=NQ+1
      DO 121 I=NG,NT
      DO 122 J=1,10
      IF (TH(I).EQ.TO(J)) GO TO 123
      IF (ND.EQ.0) GO TO 122
      IF (TH(I).EQ.TK(J)) GO TO 124
121  CONTINUE
122  IF (VM.EQ.1.0E-10) GO TO 126
123  NG=NG+1
      CALL GAUSS(IR,DFCOR,TGCRP,CORPEN)
126  IF (CORPEN.GE.360.0) CORPEN=CORPEN-360.0
      IF (CORPEN.LT.0.0) CORPEN=CORPEN+360.0
      CALL GAUSS(IR,SPDDEV,VI,PG,VT)
      IF (VT.LT.0.0) VT=ABS(VT)
      GO TO 80
      C
124  VM=VM*(NC,NH)
128  NG=NG+1
      IF (VM.EQ.1.0E-10) GO TO 109
      NH=NH+1
      GO TO 96
      C
125  IF (NT.EQ.1.AND.NG.EQ.1) GO TO 130
      IF (I.NC).LT.(TIMRES-TH(NT-1)) GO TO 131
      NC=NQ+1
      IF (VT.GE.VM.AND.XLAMP(NC).GE.90.0) GO TO 113
      IF (I.NC).GE.1.0) GO TO 113
      IF (ABS(SECL(NC)-SEC(NC)).GT.0.1) GO TO 300
      X(NC)=X(NC)-VM*(TIMRES-TH(NT-1))*C(NC)/A(NC)
      GO TO 129
130  IF (I.NC).LT.TIMRES) GO TO 131
      X(NC)=X(NC)-VM*TIMRES*C(NC)/A(NC)
      GO TO 136
131  X(NC)=X(NC)-VM*TIMRES*C(NC)/A(NC)

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```

GO TO 136
IF(NC.EQ.3) GO TO 80
129 XDELTA(NC)=ARSIN((VT/VTORP)*A(NC))
136 NC=NC+1
137 IF(NC.GT.NA) GO TO 141
CORPEN=ICORP
VT=VTARG
IR=IM
GC TO 3000

C C C C C
SUBROUTINE TILDA_CALCULATES THE RETURN OF MISPLACED
BOATS INTO THE REQUIRED SECTORS
C
300 CALL TILDA (IX,NC,NG,NC,NI,CORPEN,DEGRAD,TIMRES,VM,VT,
1SEC,SECI,TH,X,XDELTA,XLAMBDA)
C
GO TO 120
C
141 IF=TA
IS=IR
IT=IX
NW=1
AA=CORPEN
AB=VT
C
C C C C C
SUBROUTINE TERESE DETERMINES THE INITIAL GRID-POSITIONS
FOR THE BOATS
C
CALL TERESE (NA,DEGRAD,DISSTP,COORX,COORY,SECI,X)
145 DO 142 I=1,NA
IF(X(I).GT.DISSTP) GO TO 142
DO 143 J=1,4
IF(TORP(J,J).EQ.0.0) GO TO 143
CORX(I,J)=COORX(I)
COORY(I,J)=COORY(I)
143 CONTINUE
142 CONTINUE
C
ZPSI(1)=PSI*1.5
ZPSI(2)=PSI*0.5
ZPSI(3)=-ZPSI(2)
ZPSI(4)=-ZPSI(1)
TE=TF-TIMRES
C
C C C
SUBROUTINE FLA DETERMINES :

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CCCC      1. TORPEDO - COURSE, - RANGE AND - SPEED SUBJECT TO HUMAN
           AND MECHANICAL ERRORS
CCCC      CALL ELLA
           (IX,NA,CORPEN,DEGRAD,DEL,DISSIP,THE,TORDEV,TORMX,
1TORSMN,VTORP,XX,XDELTA,BXTHET,ZPSI,SECI,PI,TORP,TORCOR,TORP,X)
CCCC      SUBROUTINE EPNA CALCULATES ANGLES WITH RESPECT TO
           THE TORPEDO-COURSE
CCCC      CALL EPNA (TORP,TORCOR,DEGRAD,TANGT,SLTSIN,SLTCOS,NA,DISSTP,X)
CCCC      SUBROUTINE EMMA EVALUATES THE TORPEDO-HIT-PROBABILITY
           FOR EACH RUN
CCCC      207 CALL EMMA(SLDSIN,TORP,TORCOR,DEGRAD,CORPEN,CORX,CORY,PI,TORP,
           1COORDX,COORDY,TUNGT,SLTSIN,SLTCOS,VI,SUMHIT,TANGT,SLDCOS,NA,TE,
           2DISSTP,X,NR,NW)
           IF(NP.EQ.2) GO TO 215
CCCC      SUBROUTINE ERWIN DETERMINES THE NEXT POSITION OF THE
           TORPEDOES AND THE DESTROYER WITHIN A SPECIFIED
           TIME-INTERVAL
CCCC      CALL ERWIN (TORP,PI,TORP,TORCOR,TE,CORX,CORY,CORCORX,COORDY,
           1SLTSIN,SLTCOS,SLDSIN,SLDCOS,VI,CORPEN,NA,DISSTP,X)
CCCC      DO 208 I=1,NA
           IF(X(I).GT.DISSIP) GO TO 208
CCCC      DO 209 J=1,4
           IF(TORP(I,J).EQ.0.0) GO TO 209
CCCC      IF(PI,TORP(I,J).GT.0.0) GO TO 210
           CONTINUE
           CONTINUE
           GO TO 215
CCCC      TD=TA
           TR=IR*KR
           R=0.5+FLCAT(IR)*2.328306E-10
           TA=(-1.0/EXCH)*ALOG(R)+TA
           TE=TA-TD
CCCC      CALL GAUSS (IX,DELCOB,TGCRP,CORPEN)
           IF(CORPEN.GE.360.0) CORPEN=CORPEN-360.0
           IF(CORPEN.LT.0.0) CORPEN=CORPEN+360.0
CCCC      CALL GAUSS (IX,SPDEV,VTARG,VT)
           IF(VI.LT.0.0) VI=ABS(VT)
           GO TO 207
CCCC      209
CCCC      208
CCCC      210
CCCC      211

```



```

C 215 PSI=PSI+PSIINC
      NP=1
      NW=NW+1
      IF(NW.GT.6) GO TO 220
      CORRDX=10.0
      CORDDY=10.0
      IR=IS
      IX=IT
      CORPPFN=AA
      VI=AB
      VA=FE
      GO TO 145

C 220 NX=NX-1
      IF(NX.EQ.0) GO TO 225
      PSI=APSI
      GO TO 2000

C 225 DO 226 I=1,6
      PHIT(I)=SUMHIT(I)/NREPLI
      226 CONTINUE
      HIRZL=NHIT2/(NGNFR*TIMRES*NRGUN*NREPLI)
      AX=DISTAN
      WRITE(6,9002) TIMRES,DISTAN,PIRAT,(PHIT(I),I=1,6)
      IF(NV.GT.NU) GO TO 9999
      READ(5,3) DISTAN,TIMRES,PSI
      IF(DISTAN.LT.AXI) WRITE(6,9006)
      NX=NREPLI
      IR=IU
      IX=IV
      GO TO 1000

9999 STOP

C
C
C
C
      FORMAT - STATEMENTS

1 FORMAT(I2,I4,I3,I1,I2,I5,I5,F4.0,F3.0,F4.0,F4.0,F4.0,F3.0,
1 F5.0,F4.0,F5.0,F4.0,F4.0)
2 FORMAT(F3.0,F3.0,F4.0,F4.0,F3.0,F3.0,F4.0,F3.0)
3 FORMAT(F3.0,F4.0,F4.0)

C 9000 FORMAT(' ',///,10X,'NREPLI = ',I3,2X,'EXCH = ',F4.2,2X,'GUNLAU = ',
2 F4.2,2X)
9001 FORMAT(31X,6F6.3)
9002 FORMAT(11X,F4.1,4X,F3.1,2X,F6.4,1X,6F6.3,/)

```



```

IF(NK(NN).EQ.NK(NN+1)) GO TO 514
NN=NN+1
IF(NN.GT.NHIT) GO TO 540
GO TO 500
514 NN=NN+1
MM=MM+1
IF(NN.GT.NHIT) GO TO 540
CALL TANTA (IX,IY,P)
IF(R.LT.RTEMP) GO TO 515
PTEMP=R
GO TO 513
C
503 VMM(NK(NN),MM)=33.0/60.0
C
C
SUBROUTINE TINA DETERMINES WHICH TORPEDO-TUBE WAS HIT
CALL TINA (IX,KA,NN,NK,TORP)
CALL TINA (IX,KA,NN,NK,TORP)
IF((NN+1).GT.NHIT) NK(NN+1)= NA+1
IF(NK(NN).EQ.NK(NN+1)) GO TO 516
NN=NN+1
IF(NN.GT.NHIT) GO TO 540
GO TO 500
516 NN=NN+1
MM=MM+1
IF(NN.GT.NHIT) GO TO 540
CALL TANTA (IX,IY,P)
IF(R.LT.RTEMP) GO TO 517
PTEMP=R
GO TO 513
C
504 VMM(NK(NN),MM)=27.0/60.0
CALL TINA (IX,KA,NN,NK,TORP)
IF((NN+1).GT.NHIT) NK(NN+1)= NA+1
IF(NK(NN).EQ.NK(NN+1)) GO TO 518
NN=NN+1
IF(NN.GT.NHIT) GO TO 540
GO TO 500
518 NN=NN+1
MM=MM+1
IF(NN.GT.NHIT) GO TO 540
CALL TANTA (IX,IY,P)
IF(R.LT.RTEMP) GO TO 519
PTEMP=R
GO TO 513
C
505 VMM(NK(NN),MM)= 27.0/60.0
CALL TINA (IX,KA,NN,NK,TORP)

```



```

CALL TINA (IX,KA,NN,NK,TORP)
IF((NN+1).GT.NHIT) NK(NN+1)= NA+1
IF(NK(NN).EQ.NK(NN+1)) GO TO 520
NN=NN+1
IF(NN.GT.NHIT) GO TO 540
GO TO 500
520 NN=NN+1
MM=MM+1
IF(NN.GT.NHIT) GO TO 540
521 CALL TANTE (IX,IY,R)
IF(R.LI.FTEMP) GO TO 521
RTMP=R
GO TO 513

C
506 VM(NK(NN),MM)=27.0/60.0
CALL TINA (IX,KA,NN,NK,TORP)
CALL TINA (IX,KA,NN,NK,TORP)
CALL TINA (IX,KA,NN,NK,TORP)
IF((NN+1).GT.NHIT) NK(NN+1)= NA+1
IF(NK(NN).EQ.NK(NN+1)) GO TO 522
NN=NN+1
IF(NN.GT.NHIT) GO TO 540
GO TO 500
522 NN=NN+1
MM=MM+1
523 CALL TANTE (IX,IY,R)
IF(NN.GT.NHIT) GO TO 540
IF(R.LI.FTEMP) GO TO 523
RTMP=R
GO TO 513

C
507 VM(NK(NN),MM)=18.0/60.0
CALL TINA (IX,KA,NN,NK,TORP)
IF((NN+1).GT.NHIT) NK(NN+1)= NA+1
IF(NK(NN).EQ.NK(NN+1)) GO TO 524
NN=NN+1
IF(NN.GT.NHIT) GO TO 540
GO TO 500
524 NN=NN+1
MM=MM+1
IF(NN.GT.NHIT) GO TO 540
525 CALL TANTE (IX,IY,R)
IF(R.LI.FTEMP) GO TO 525
RTMP=R
GO TO 513

C
508 VM(NK(NN),MM)=18.0/60.0
CALL TINA (IX,KA,NN,NK,TORP)

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```

CALL TINA (IX,KA,NN,NK,TORP)
IF((NN+1).GT.NHIT) NK(NN+1)= NA+1
IF(NK(NN).EQ.NK(NN+1)) GO TO 526
NN=NN+1
IF(NN.GT.NHIT) GO TO 540
GO TO 500
526 NN=NN+1
MM=MM+1
IF(NN.GT.NHIT) GO TO 540
527 CALL TANTE (IX,IY,R)
IF(R.LT.RTEMP) GO TO 527
RTEMP=R
GO TO 513
C
509 VMM(NK(NN),MM)=18.0/60.0
CALL TINA (IX,KA,NN,NK,TORP)
CALL TINA (IX,KA,NN,NK,TORP)
CALL TINA (IX,KA,NN,NK,TORP)
IF((NN+1).GT.NHIT) NK(NN+1)= NA+1
IF(NK(NN).EQ.NK(NN+1)) GO TO 528
NN=NN+1
IF(NN.GT.NHIT) GO TO 540
GO TO 500
528 NN=NN+1
MM=MM+1
IF(NN.GT.NHIT) GO TO 540
529 CALL TANTE (IX,IY,R)
IF(R.LT.RTEMP) GO TO 529
RTEMP=R
GO TO 513
C
510 VMM(NK(NN),MM)=1.0E-10
531 IF((NN+1).GT.NHIT) NK(NN+1)=NA+1
IF(NK(NN).EQ.NK(NN+1)) GO TO 532
NN=NN+1
IF(NN.GT.NHIT) GO TO 540
GO TO 500
532 NN=NN+1
IF(NN.GT.NHIT) GO TO 540
GO TO 531
540 RETURN
END

```



```

C      SUBROUTINE ELLA(IX,NA,CORPEN,DEGRAD,DEL,DISSTP,THE,TORDEV,TORRMX,
C      1TORSMN,VTORP,XX,XDELTA,BXTHET,ZPSI,SECI,RITORP,TORCOR,TORP,X)
C
C      DIMENSION XDELTA(10),PXTHET(10,4),ZPSI(4),ASEC(10),
C      1SECI(10),RITORP(10,4),TORCOR(10,4),TORP(10,4),X(10)
C
C      DO 150 I=1,NA
C      IF(X(I).GT.DISSIP) GO TO 150
C      CALL GAUSS(IX,REL,XDELTA,XDELTA)
C      ASEC(I)=SECI(I)+180.0
C      IF(ASEC(I).GE.360.0) ASEC(I)=ASEC(I)-360.0
C      AC=CORPEN-SECI(I)
C      DO 160 J=1,4
C      IF(TORP(I,J).EQ.0.0) GO TO 160
C      CALL GAUSS(IX,TORDEV,VTORP,TORP)
C      PXTHET(I,J)=XDELTA(J)/DEGRAD-ZPSI(J)
C      CALL GAUSS(IX,THE,BXTHET,BXTHET)
C      RITORP(I,J)=XX*(TORP(I,J)-TORSMN)+TORRMX
C      IF(AC.GE.0.0.AND.AC.LE.180.0) GO TO 155
C      IF(AC.LE.(-180.0)) GO TO 155
C      IF(AC.LT.0.0.AND.AC.GT.(-180.0)) GO TO 156
C      IF(AC.GT.180.0) GO TO 156
C      AB=ASEC(I)-BXTHET(I,J)
C      GO TO 159
C      155 AB=ASEC(I)+BXTHET(I,J)
C      156 AB=ASEC(I)+BXTHET(I,J)
C      159 IF(AB.LT.0.0) AB=AB+360.0
C      IF(AB.GE.360.0) AB=AB-360.0
C      TORCOR(I,J)=AB
C      CONTINUE
C      160 RETURN
C      END
C
C      SUBROUTINE EMIL (R,AX,D,IE)
C
C      IE=0
C      AX=.99999E+74
C      D=AX
C      IF(R) 81,84,82
C      81 IE=1
C      GO TO 82
C      82 IF(R-1.0)87,85,81
C      84 AX=-.999999E+74
C      85 D=0.0
C      GO TO 92

```



```

87 D=R
88 IF(D-0.5) 89,89,88
89 D=1.0-D
90 T2=ALOG(1.0/(D*D))
91 T=SQRT(T2)
92 AX=T-(2.515517+0.802853*T+0.010328*T2)/(1.0+1.432788*T+C.189269*T
12+0.001308*T*T2)
93 IF(D-0.5)90,90,91
90 AX=-AX
91 D=C.3989423*EXP(-AX*AX/2.0)
92 RETURN
END

SUBROUTINE FMMAL(SLDSIN,TQEP,TORCOR,DEGRAD,CORPEN,CORX,CORY,
R1TORP,COORDX,COORDY,TLNGTH,SLTSIN,SLTCOS,VT,SUMHIT,TANGT,
2SLDCOS,NA,TE,DISSTP,X,NR,NW)

C
C
C DIMENSION TORP(10,4),TORCOR(10,4),CORX(10,4),CORY(10,4),R1TORP(
110,4),SLTSIN(10,4),SLTCOS(10,4),TANGT(10,4),X(10),SUMHIT(6)

IF(CORPEN.GT.90.0) GO TO 221
BETA=(90.0-CORPEN)*DEGRAD
SLDSIN=SIN(BETA)
SLDCOS=COS(BETA)
TANGD=SLDSIN/SLDCOS
GO TO 230

221 IF(CORPEN.GT.180.0) GO TO 222
BETA=(CORPEN-90.0)*DEGRAD
SLDSIN=SIN(BETA)
SLDCOS=COS(BETA)
TANGD=-SLDSIN/SLDCOS
GO TO 230

222 IF(CORPEN.GT.270.0) GO TO 223
BETA=(270.0-CORPEN)*DEGRAD
SLDSIN=SIN(BETA)
SLDCOS=COS(BETA)
TANGD=SLDSIN/SLDCOS
GO TO 230

223 BETA=(CORPEN-270.0)*DEGRAD
SLDSIN=SIN(BETA)
SLDCOS=COS(BETA)
TANGD=-SLDSIN/SLDCOS

C
C
230 DO 215 I=1,NA
IF(X(I).GT.DISSTP) GO TO 215

```



```

D7 216 J=1,4
IF (TORP(I,J).EQ.0.0) GO TO 216
AA=TANGT(I,J)-TANGD
IF (AA.LT.1.0E-5) AA=1.0E-5
XINGX=(TANGT(I,J)*CORX(I,J)-TANGD*COORDX+COORDY-CORY(I,J))/AA
XINGY=TANGD*(XINGX-COORDX)+COORDY

C
C
IF (CORPEN.GE.90.0) GO TO 231
GO TO 233
231 IF (CORPEN.GE.180.0) GO TO 232
GO TO 234
232 IF (CORPEN.GE.270.0) GO TO 236
GO TO 235
233 IF (XINGX.LT.COORDX.OR.XINGY.LT.COORDY) GO TO 216
GO TO 240
234 IF (XINGX.LT.COORDX.OR.XINGY.GT.COORDY) GO TO 216
GO TO 240
235 IF (XINGX.GT.COORDX.OR.XINGY.LT.COORDY) GO TO 216
GO TO 240
236 IF (XINGX.GT.COORDX.OR.XINGY.GT.COORDY) GO TO 216
240 AB=SLTCOS(I,J)
IF (AB.LT.1.0E-5) AR=1.0E-5
DISONE=ABS(XINGX-CORX(I,J))/AB
IF (DISONE.GT.1TORP(I,J)) GO TO 216
IF (SLDCOS.LT.1.0E-5) SLDCOS=1.0E-5
DISTWO=ABS(XINGX-COORDX)/SLDCOS
IF (DISTWO.GT.1TORP(I,J))
IF (IT.GT.IT) GO TO 216
DISTHRE=IT*VT
DISER=DISTR-DISTWO
IF (DISER.LT.0.0) GO TO 216
IF (DISER.LE.TLNGTH) GO TO 218
216 CONTINUE
215 CONTINUE
GO TO 219
218 SUMHIT(NW)=SUMHIT(NW)+1.0
NR=NR+1
219 RETURN
END

SUBROUTINE EPNA (TORP,TORCOR,DEGRAD,TANGT,SLTSIN,SLTCOS,NA,DISSTP
1,X)
C
C DIMENSION TORP(10,4),TORCOR(10,4),SLTSIN(10,4),SLTCOS(10,4),
1 TANGT(10,4),X(10)

```


C

```

210 I=1,NA
IF(X(I).GT.DISSSTP) GO TO 210
DO 211 J=1,4
IF(TORP(I,J).EQ.0.0) GO TO 211
IF(TORCOR(I,J).GT.90.0) GO TO 212
ALPHA=(90.0-TORCOR(I,J))*DEGRAD
SLTSIN(I,J)=SIN(ALPHA)
SLTCOS(I,J)=COS(ALPHA)
TANGT(I,J) = SLTSIN(I,J)/SLTCOS(I,J)
GO TO 211
212 IF(TORCOR(I,J).GT.180.0) GO TO 213
ALPHA=(TORCOR(I,J)-90.0)*DEGRAD
SLTSIN(I,J)=SIN(ALPHA)
SLTCOS(I,J)=COS(ALPHA)
TANGT(I,J) = -SLTSIN(I,J)/SLTCOS(I,J)
GO TO 211
213 IF(TORCOR(I,J).GT.270.0) GO TO 214
ALPHA=(270.0-TORCOR(I,J))*DEGRAD
SLTSIN(I,J)=SIN(ALPHA)
SLTCOS(I,J)=COS(ALPHA)
TANGT(I,J) = SLTSIN(I,J)/SLTCOS(I,J)
GO TO 211
214 ALPHA=(TORCOR(I,J)-270.0)*DEGRAD
SLTSIN(I,J)=SIN(ALPHA)
SLTCOS(I,J)=COS(ALPHA)
TANGT(I,J) = -SLTSIN(I,J)/SLTCOS(I,J)
211 CONTINUE
210 RETURN
END

SUBROUTINE ERWIN (TORP,RTTORP,TORCOR,TE,CORX,CORY,COORDX,COORDY,
1SLTSIN,SLTCOS,SLDSIN,SLDCOS,VF,CORPEN,NA,DISSSTP,X)
DIMENSION TORP(10,4),RTTORP(10,4),TORCOR(10,4),CORX(10,4),
1CORY(10,4),SLTSIN(10,4),SLTCOS(10,4),X(10)

C
C
C
250 DO 251 I=1,NA
IF(X(I).GT.DISSSTP) GO TO 251
DO 252 J=1,4
IF(TORP(I,J).EQ.0.0.OR.RTTORP(I,J).LT.0.0) GO TO 252
XXX=TE*TORP(I,J)
RTTORP(I,J)=RTTORP(I,J)-XXX
IF(TORCOR(I,J).GT.90.0) GO TO 253
CORX(I,J)=CORX(I,J)+XXX*SLTCOS(I,J)

```



```

253 CCRX(I,J)=CCRY(I,J)+XXX*SLTSIN(I,J)
GO TO 252
IF (TORCOR(I,J).GT.180.0) GO TO 254
CCRX(I,J)=CCRX(I,J)+XXX*SLDCOS(I,J)
CCRY(I,J)=CCRY(I,J)-XXX*SLTSIN(I,J)
GO TO 252
254 IF (TORCOR(I,J).GT.270.0) GO TO 255
CCRX(I,J)=CCRX(I,J)-XXX*SLDCOS(I,J)
CCRY(I,J)=CCRY(I,J)+XXX*SLTSIN(I,J)
GO TO 252
255 CCRX(I,J)=CCRX(I,J)-XXX*SLDCOS(I,J)
CCRY(I,J)=CCRY(I,J)+XXX*SLTSIN(I,J)
252 CONTINUE
251 CONTINUE

```

C C

```

IF (CORPEN.GT.90.0) GO TO 257
CCORDX=CCORDX+TE*VT*SLDCOS
CCORDY=CCORDY+TE*VT*SLDSIN
GO TO 260
257 IF (CORPEN.GT.180.0) GO TO 258
CCORDX=CCORDX+TE*VT*SLDCOS
CCORDY=CCORDY-TE*VT*SLDSIN
GO TO 260
258 IF (CORPEN.GT.270.0) GO TO 259
CCORDX=CCORDX-TE*VT*SLDCOS
CCORDY=CCORDY-TE*VT*SLDSIN
GO TO 260
259 CCRDX=CCORDX-TE*VT*SLDCOS
CCORDY=CCORDY+TE*VT*SLDSIN
260 RETURN
END

```

SUBROUTINE TANTE (IX,IY,R)

C C

```

IY=IX*65539
IF (IY)5,6,6
5 IY=IY+2147483647+1
6 P=IY
IX=IY
R=R*.4656613E-9
RETURN
END

```



```

C
C
SUBROUTINE TERESE (NA,DEGRAD,DISSTP,COORDX,COORDY,SECI,X)
C
C
  DIMENSION COORDX(10),COORDY(10),SECI(10),X(10)

  DO 142 I=1,NA
    IF(X(I).GT.DISSTP) GO TO 142
    IF(SECI(I).GT.90.0) GO TO 143
    ALPHA=SECI(I)*DEGRAD
    COORDX(I)=10.0+X(I)*SIN(ALPHA)
    COORDY(I)=10.0+X(I)*COS(ALPHA)
    GO TO 142
  143 IF(SECI(I).GT.180.0) GO TO 144
    ALPHA=(SECI(I)-90.0)*DEGRAD
    COORDX(I)=10.0+X(I)*COS(ALPHA)
    COORDY(I)=10.0-X(I)*SIN(ALPHA)
    GO TO 142
  144 IF(SECI(I).GT.270.0) GO TO 145
    ALPHA=(SECI(I)-180.0)*DEGRAD
    COORDX(I)=10.0-X(I)*SIN(ALPHA)
    COORDY(I)=10.0-X(I)*COS(ALPHA)
    GO TO 142
  145 ALPHA=(SECI(I)-270.0)*DEGRAD
    COORDX(I)=10.0-X(I)*COS(ALPHA)
    COORDY(I)=10.0+X(I)*SIN(ALPHA)
  142 CONTINUE
C
C
  RETURN
  END
C
C
SUBROUTINE TILDA (IX,NC,NG,NQ,NT,CORPEN,DEGRAD,TIMRES,VM,VT,
C
C
  1 SEC,SECI,TH,X,XDELTA,XLAMBDA)
C
C
  DIMENSION SEC(10),SECI(10),TH(30),X(10),XDELTA(10),XLAMBDA(10)

  XI=XDELTA(NC)/DEGRAD
  X2=X1/10.0
  IF(CORPEN.LT.180.0) GO TO 306
  IF(SECI(NC).GT.CORPEN.DR.SECI(NC).LT.(CORPEN-180.0)) GO TO 303
  301 CALL GAUSS (IX,X2,X1,X3)
    IF(X3.LT.X1) GO TO 301
    GO TO 312
  302 CALL GAUSS (IX,X2,X1,X3)
    IF(X3.GT.X1) GO TO 302
    GO TO 312

```



```

303 IF (SECI(NC).GT.SEC(NC)) GO TO 305
304 CALL GAUSS (IX,X2,X1,X3)
   IF (X3.GT.X1) GO TO 304
   GO TO 312
305 CALL GAUSS (IX,X2,X1,X3)
   IF (X3.LT.X1) GO TO 305
   GO TO 312
306 IF (SECI(NC).GT.CORPEN.DR.SECI(NC).LT.(CORPEN+180.0)) GO TO 308
   IF (SECI(NC).GT.SEC(NC)) GO TO 308
307 CALL GAUSS (IX,X2,X1,X3)
   IF (X3.LT.X1) GO TO 307
   GO TO 312
308 CALL GAUSS (IX,X2,X1,X3)
   IF (X3.GT.X1) GO TO 308
   GO TO 312
309 IF (SECI(NC).GT.SEC(NC)) GO TO 311
310 CALL GAUSS (IX,X2,X1,X3)
   IF (X3.GT.X1) GO TO 310
   GO TO 312
311 CALL GAUSS (IX,X2,X1,X3)
   IF (X3.LT.X1) GO TO 311
   IF (NG.EQ.1) GO TO 315
   IF (TH(NG)-TH(NG-1))
     GO TO 320
   IF (TH(NG))
     GO TO 320
   IF (NG.EQ.3) TE=TIMRES-TH(NT-1)
   X1=VM*TE
   X2=VT*TE*DEGRAD
   X3=X3*DEGRAD
   IF (X3.LT.1.0E-5) X3=0.0
   V=(X1**2+X(NC)**2-2.0*X1*X(NC)*COS(X3))**.5
   X1=X1*SIN(X3)/V
   IF (X1.LT.1.0E-5) X1=0.0
   ETA=ARSIN(X1)/DEGRAD
   BETA=(XLAMBDA(NC)-ETA)*DEGRAD
   IF (BETA.LT.1.0E-5) BETA=0.0
   X(NC)=(X2**2+V**2-2.0*X2*V*COS(BETA))**.5
   X2=V*SIN(BETA)/X(NC)
   IF (X2.LT.1.0E-5) X2=0.0
   X1=ARSIN(X2)/DEGRAD
   IF (XLAMRD(NC).LT.90.0) X1=180.0-X1
   XLAMRD(NC)=180.0-X1
   IF (CORPEN.LT.180.0) GO TO 330
   IF (SECI(NC).GT.CORPEN.DR.SECI(NC).LT.(CORPEN-180.0)) GO TO 325
   SECI(NC)=CORPEN-XLAMRD(NC)
   IF (SECI(NC).LT.0.0) SECI(NC)=SECI(NC)+360.0
   GO TO 332
325 SECI(NC)=CORPEN+XLAMRD(NC)

```



```

IF (SECI(NC).GT.360.0) SECI(NC)=SECI(NC)-360.0
GO TO 332
IF (SECI(NC).LT.CORPEN.OR.SECI(NC).GT.(CORPEN+180.0)) GO TO 331
SECI(NC)=CORPEN+XLAMPD(NC)
IF (SECI(NC).GT.360.0) SECI(NC)=SECI(NC)-360.0
GO TO 332
331 SECI(NC)=CORPEN-XLAMPD(NC)
IF (SECI(NC).LT.0.0) SECI(NC)=SECI(NC)+360.0
RETURN
END

SUBROUTINE TINA (IX,KA,NN,NK,TORP)
DIMENSION TOPP(10,4),NK(50)
C
C
CALL TANTE (IX,IY,R)
KA=4.0/R+0.5
IF (KA.LT.1) KA=1
TORP(NK(NN),KA)=0.0
RETURN
END

```


LIST OF REFERENCES

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